

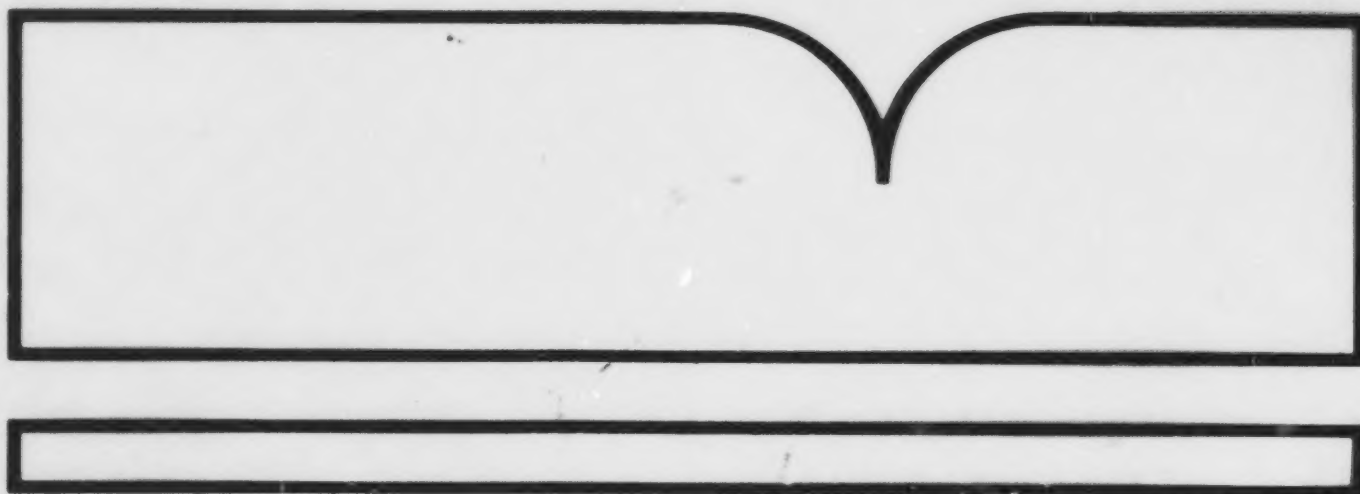
Nationwide Urban Runoff
Program, Upper Mystic Lake
Watershed: Case Study

Massachusetts Dept. of Environmental Quality
Engineering, Boston

Prepared for

Environmental Protection Agency, Washington, DC

Oct 82



U.S. Department of Commerce
National Technical Information Service

NTIS

CDM

environmental engineers, scientists,
planners, & management consultants

PB85-110690

CAMP DRESSER & MCKEE INC.

One Center Plaza
Boston, Massachusetts 02108
617 742-5151

UPPER MYSTIC LAKE WATERSHED

NATIONWIDE URBAN RUNOFF

CASE STUDY

prepared for:

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING

by

CAMP DRESSER & MCKEE INC.
ONE CENTER PLAZA
BOSTON, MASSACHUSETTS 02108

October 1982

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB8 5 110690
4. Title and Subtitle Nationwide Urban Runoff Program, Upper Mystic Lake Watershed, CASE STUDY.		5. Report Date October, 1982	
7. Author(s) Guillermo J Vicens, CAMP, DRESSER & MCKEE, INC.		8. Performing Organization Rept. No.	
9. Performing Organization Name and Address DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING Commonwealth of Massachusetts One Winter Street Boston, MA 02108		10. Project/Task/Work Unit No.	
		11. Contract(C) or Grant(G) No. (C) (G) P-001114016	
12. Sponsoring Organization Name and Address EPA, Office of Water Program Operations Water Planning Division 401 M Street, SW Washington, D C 20460		13. Type of Report & Period Covered Final, 1978-1982	
15. Supplementary Notes		14.	
16. Abstract (Limit: 200 words) This report was prepared to: summarize the analysis of hydrologic and water quality data, both historic and as collected during the study; demonstrate the application of the STORM simulation model to characterize the rainfall/runoff and pollutant washoff processes that are taking place; summarize simulation of the ABERJONA River quality using the model RWQM; demonstrate further application of the two models to predict the loadings of various constituents to Upper Mystic Lake; and provide identification of control alternatives and preliminary screening of those that are practical, effective, feasible and implementable.			
17. Document Analysis			
a. Descriptors			
Hydrology	Water pollution	Storms	Civil Engineering
Urban development	Water resources	Regional planning	
Watersheds	Sedimentation	Urban planning	
b. Identifiers/Open-Ended Terms			
Runoff	Soil Erosion	Storm Drains	
Streamflow	Water Quality	Urbanization	
Stream pollution	Sediments	Land use	
Rainfall	Sediment Transport		
Snowmelt	Suspended Solids		
c. COSATI Field/Group			
18. Availability Statement: No restriction on distribution. Available from National Technical Information Service, Springfield, VA 22161		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 178
		20. Security Class (This Page) UNCLASSIFIED	22. Price

LIST OF TABLES (continued)

		<u>Page</u>
Table 4.4	Hydraulic Parameters Used in RWQM	4-14
Table 4.5	USGS Field-Measured Versus RWQM-Simulated Travel Times	4-15
Table 4.6	Contribution to Baseflow by Storm Subbasin	4-17
Table 4.7	RWQM Calibration Results	4-21
Table 4.8	Annual Total Phosphorus Loading to Lake	4-23
Table 4.9	RWQM Sensitivity to Varying Coliform Dieoff Rates	4-25
Table 4.10	Sensitivity Analysis for Dry and Wet Weather Coliform Concentrations	4-26
Table 4.11	Sensitivity Analyses for RWQM Volumetric Status	4-28
Table 4.12	Annual Loadings for Principal Constituents to Upper Mystic Lake	4-29
Table 4.13	Metals Loads to Upper Mystic Lake	4-30
Table 5.1	Conversion Table for Annual Phosphorus Loadings	5-3
Table 5.2	Mean and Maximum Phosphorus Concentrations in the Aberjona River for Different Removal Rates	5-7
Table 5.3	Retention Times in Forebays	5-11
Table 5.4	Dilution Rates in Forebays	5-11
Table 5.5	Effects of Control Strategies on Coliform Levels at Sandy Beach due to Loads from Aberjona	5-13
Table 5.6	Removal Efficiencies for Controls	5-20
Table 5.17	Summary of Control Measure Screening	5-25

LIST OF TABLES (continued)

		<u>Page</u>
Table 2.23	Metals Load and Concentration Summary for Sweetwater	2-32
Table 2.24	Ratios of Filtered to Nonfiltered Concentrations for end of Pipes and Aberjona River	2-34
Table 2.25	UML Watershed Concentrations <u>vs.</u> Literature Values	2-36
Table 3.1	Land Use of Storm Subbasins	3-11
Table 3.2	Runoff Coefficients and Depression Storage Volumes Used in Storm Simulations	3-13
Table 3.3	Pollutant Buildup Rates at End of Pipe Stations	3-15
Table 3.4	Buildup Rates Used in Storm Calibration	3-19
Table 3.5	Representative Measured Pollutant Buildup Rates	3-20
Table 3.6	Results of Storm Calibration	3-21
Table 3.7	Results of STORM Sensitivity Analysis Mishawum Subbasin	3-23
Table 3.8	Buildup Rates and Land Uses for Subbasins with No Field-Measured Data	3-24
Table 3.9	Average Annual Pollutant Washoff in Upper Mystic Lake Watershed	3-26
Table 3.10	TSS Washoff by Season	3-27
Table 3.11	Nitrate-Nitrogen Washoff by Season	3-27w
Table 3.12	TKN Washoff by Season	3-28
Table 3.13	Orthophosphate Washoff by Season	3-29
Table 3.14	Total Phosphorus Washoff by Season	3-30
Table 3.15	BOD Washoff by Season	3-31
Table 3.16	Total Pollutant Washoff for Horn Pond Subbasin with Drainage Area Upstream of Pond Included	3-32
Table 3.17	Land Use and Estimated Runoff Coefficients For Direct Lake Drainage	3-33
Table 4.1	Percentile Curve at USGS Gauge	4-6
Table 4.2	Continuous Dry Weather Total Phosphorus and Total Coliform Concentrations	4-8
Table 4.3	Key Locations in the Aberjona Basin	4-11

LIST OF TABLES

		<u>Page</u>
Table 1.1	Class B Water Quality Standards	1-4
Table 2.1	Sampling Stations	2-3
Table 2.2	Water Quality Constituents and Abbreviations	2-5
Table 2.3	Runoff Coefficients: Unadjusted and Revised	2-8
Table 2.4	Water Quality Constituent Load and Concentration Summary for Hemlock Road	2-9
Table 2.5	Water Quality Constituent Load and Concentration Summary for Addison Wesley	2-10
Table 2.6	Water Quality Constituent Load and Concentration Summary for Mishawum Road	2-11
Table 2.7	Water Quality Constituent Load and Concentration Summary for Mill Street	2-12
Table 2.8	Water Quality Constituent Load and Concentration Summary for Washington St.	2-13
Table 2.9	Water Quality Constituent Load and Concentration Summary for USGS Gauge	2-14
Table 2.10	Water Quality Constituent Load and Concentration Summary for Sweetwater Brook	2-15
Table 2.11	DEQE Sampling Stations	2-17
Table 2.12	Summary of MRWA Water Quality Data	2-19
Table 2.13	Partial Summary of DEQE Water Quality Data	2-20
Table 2.14	Results of Flow Correlation Analysis for the USGS Gauge Data	2-22
Table 2.15	Loads by Storm for Metals	2-24
Table 2.16	Loads by Storm for Metals	2-25
Table 2.17	Metals Load and Concentration Summary for Hemlock Road	2-26
Table 2.18	Metals Load and Concentration Summary for Addison-Wesley	2-27
Table 2.19	Metals Load and Concentration Summary for Mishawum	2-28
Table 2.20	Metals Load and Concentration Summary for Mill Street	2-29
Table 2.21	Metals Load and Concentration Summary for Washington Street	2-30
Table 2.22	Metals Load and Concentration Summary for USGS Gauge	2-31

		<u>Page</u>
CHAPTER 4	ANALYSIS OF THE IMPACTS OF STORMWATER DISCHARGES ON THE ABERJONA RIVER	4-1
4.1	Introduction	4-1
4.2	Analysis Methods	4-4
4.3	Data Base	4-7
4.4	RWQM Application	4-9
4.5	Summary	4-27
CHAPTER 5	SIMULATION OF CONTROL ALTERNATIVES	5-1
5.1	Introduction	5-1
5.2	Effects of Implementing Control Strategies on Water Quality	5-1
5.3	Control Measures	5-12
5.4	Summary	5-26
CHAPTER 6	SUMMARY	6-1
APPENDIX A	MYSTIC NURP STUDY WATER QUALITY DATA	A-1
APPENDIX B	RESULTS OF FIRST FLUSH ANALYSIS	B-1
APPENDIX C	PERCENTILE CURVES	C-1
APPENDIX D	BIBLIOGRAPHY	D-1

TABLE OF CONTENTS

		<u>Page</u>
CHAPTER 1	INTRODUCTION	1-1
1.1	General Description	1-1
1.2	Existing Conditions	1-3
1.3	Objectives of Study	1-6
1.4	Problem Water Quality Constituents	1-7
1.5	Previous Studies & Other Data Sources	1-7
1.6	Products of the Study	1-8
1.7	Organization of the Report	1-9
CHAPTER 2	SYNTHESIS OF FIELD SAMPLING DATA	2-1
2.1	Introduction	2-1
2.2	Water Quality Characteristics - EDP Data	2-1
2.3	Water Quality Characteristics - MRWA & DEQE Grab Sample Data	2-16
2.4	Wet vs. Dry Weather Characteristics	2-18
2.5	Heavy Metals & Priority Pollutant Data	2-21
2.6	Stormwater Quality Characteristics	2-23
2.7	Comparisons with Other Data	2-35
CHAPTER 3	CHARACTERISTICS OF URBAN RUNOFF QUANTITY & QUALITY FOR THE UPPER MYSTIC LAKE WATERSHED	3-1
3.1	Model Application and Philosophy	3-1
3.2	STORM Model Parameter Values for the Upper Mystic Lake Watershed	3-6
3.3	Basin Segmentation	3-6
3.4	Baseflow	3-7
3.5	Calibration of STORM for Hydrology	3-9
3.6	Calibration of STORM Pollutant Loadings	3-12
3.7	Results of STORM Calibration	3-25
3.8	Pollutant Load Computation for Direct Lake Drainage	3-34
3.9	Summary	3-34

LIST OF FIGURES

		<u>Page</u>
Figure 1.1	Upper Mystic Lake Basin	1-2
Figure 2.2	Upper Mystic Lake Basin	2-4
Figure 2.2	Illustration of Theissen Method in Upper Mystic Lake Watershed	2-7
Figure 3.1	STORM Schematic	3-2
Figure 3.2	Fraction of Maximum Accumulation as a Function of Time for Different Half Saturation Constants as Simulated by STORM	3-5
Figure 3.3	Segmentation of Upper Mystic Lake Watershed into STORM Subbasins	3-8
Figure 3.4	Land Use in Upper Mystic Basin	3-10
Figure 3.5	Phosphate Loads <u>vs.</u> Antecedent Dry Period at Hemlock Road	3-16
Figure 3.6	Phosphate Loads <u>vs.</u> Antecedent Dry Period at Addison-Wesley	3-17
Figure 4.1	Aberjona River Stationing	4-10
Figure 4.2	Linking of Storm Subbasins with RWQM	4-12
Figure 4.3	Field-Measured <u>vs.</u> RWQM - Simulated Total Phosphorus Concentrations	4-22
Figure 5.1	Nutrient Loading/Upper Mystic Lake Trophic Status - Main Basin Only	5-4
Figure 5.2	Nutrient Loading/Upper Mystic Lake Trophic Status - Main Basin and Two Forebays	5-5
Figure 5.3	Upper Mystic Lake Trophic Status with Different Control Strategies	5-8
Figure 5.4	Influence Curve: Sweetwater Coliform Levels <u>vs.</u> Gauge Coliform Levels	5-14
Figure 5.5	Gauge Coliform Levels <u>vs.</u> Beach Coliform Levels	5-15
Figure 5.6	Baseflow Phosphorus Concentration <u>vs.</u> Baseflow Phosphorus Load	5-27
Figure 5.7	Influence Curve: Phosphorus Washed Off Land Surface <u>vs.</u> Phosphorus Load at Gauge from Urban Runoff	5-28

CHAPTER 1

INTRODUCTION

1.1 General Description

The Upper Mystic Lake watershed is approximately 28 square miles of largely urbanized land. Most of this area - 25 square miles - is drained by the Aberjona River and its tributaries. The remaining area drains directly to the lake. The lake is a major recreational facility providing boating and swimming facilities for residents of the watershed and nearby communities. Fishing has been enjoyed in the past, and the lake was stocked with trout, but this practice was discontinued due to water quality conditions. Figure 1.1 illustrates the general location of the study area and its major tributary watersheds.

During the two decades from 1950 to 1970 the study area underwent a tremendous urban expansion. Population increased approximately sixty percent and total acreage under some form of urban land use climbed to nearly fifty percent of the available land area. Although the pace of urbanization and population growth has leveled off somewhat, it is estimated that nearly sixty percent of the drainage area to Upper Mystic Lake will be developed by the mid-1990s.

The Metropolitan District Commission (MDC) maintains a public swimming beach - "Sandy Beach" - in the lake. During the swimming season the MDC conducts weekly water quality surveys, measuring fecal and total coliforms at the beach. If the analytical results of a given survey show high coliform counts, the sampling efforts are repeated more frequently. The MDC would post the Sandy Beach area with a sign saying "Water Polluted Today: Swimming May be Hazardous," if either of the following conditions exist:

1. If one sample was taken and fecal coliform counts exceed 500 MPN/100 ml.
2. If three samples were taken, and two out of the three had fecal coliform counts exceeding 500 MPN/100 ml.

The beach has been posted periodically during the last few summers, including the summer of 1982. Continued urbanization of the Upper Mystic Lake watershed increases the likelihood that unacceptable coliform levels may impose temporary restrictions on swimming opportunities in the future.

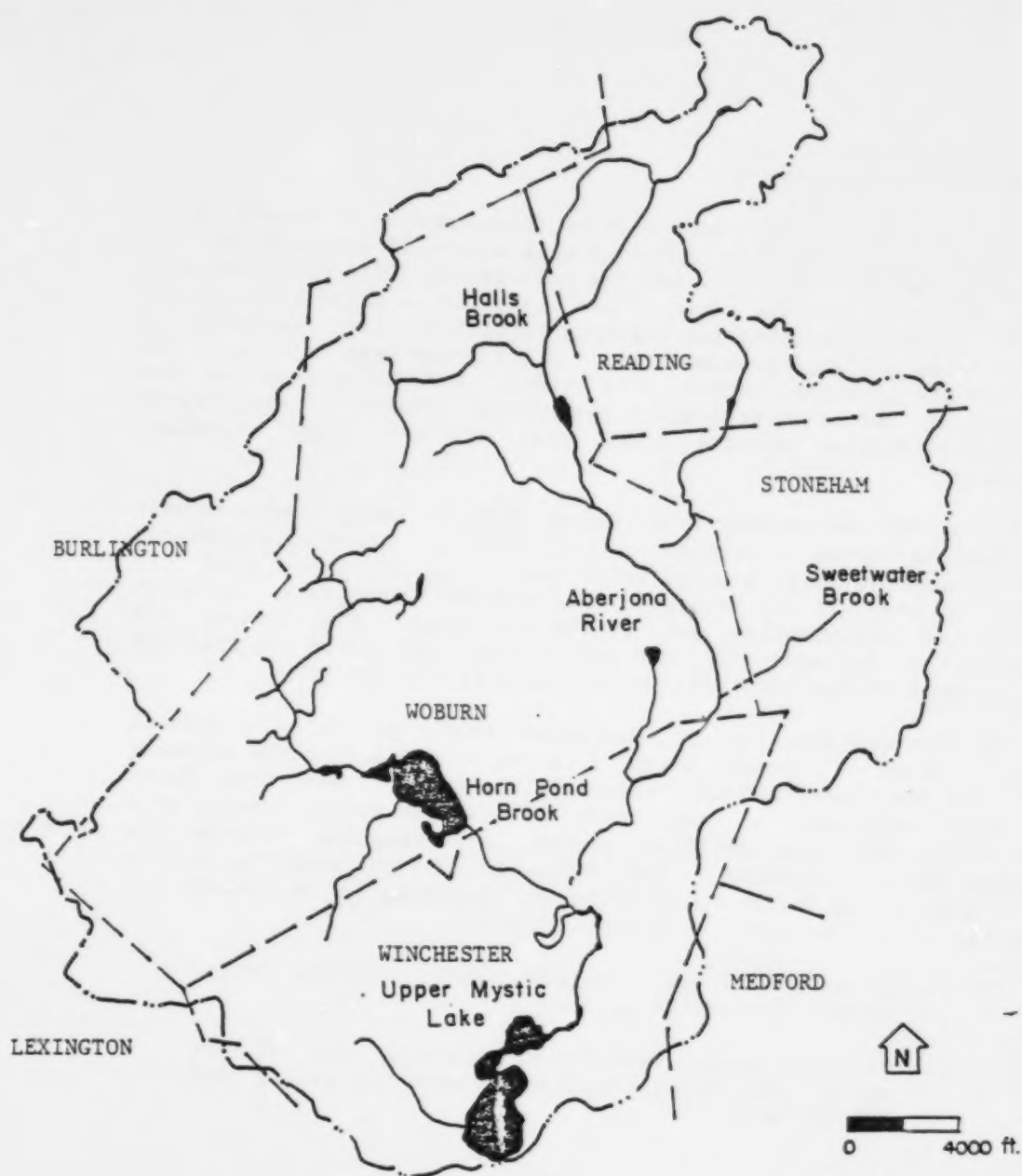


FIGURE I.1
UPPER MYSTIC LAKE BASIN
~ ~ ~ Basin Boundary

1.2 Existing Conditions

The entire Upper Mystic Lake watershed is classified as B, which is suitable for contact recreation and water supply after treatment. The class B standards are presented in detail in Table 1.1.

At present, deteriorating water quality conditions in the Aberjona River and Upper Mystic Lake threaten recreational opportunities. Recent and on-going efforts at the state and local levels have been directed toward eliminating the adverse impacts of point source discharges. However, there are no wastewater treatment plant discharges in the watershed, and virtually all pollutants enter the watershed via urban runoff or sanitary sewerage cross-connections with the storm sewer system. The identity and sources of the major pollutants in the system are the subject of this study.

Recreational opportunities at Upper Mystic Lake in the future are threatened by:

1. High coliform counts at a local swimming beach;
2. High nutrient loadings and related anaerobic hypolimnion, which promotes the growth of nuisance vegetation.

Existing water quality data indicate that the Upper Mystic Lake is rich in the plant nutrients nitrogen and phosphorus. This condition has promoted the growth of nuisance vegetation in portions of the lake. Sandy Beach was temporarily closed in 1975 and 1977 for chemical treatment of aquatic weeds. The two shallow forebays which precede the main body of the lake have been chemically treated for weed and/or water lily control in 1970, 1971, 1972, 1973, 1974, 1976 and 1978. The main body of the lake has not been treated for weed control although much of the shallow shoreline exhibits aquatic vegetation.

Continued urbanization of the watershed has increased nutrient loadings to the lake, which accelerates the natural process of eutrophication. The hypolimnion of the lake is anaerobic in the summer, which leaves the lake unacceptable for the support of a cold water fishery. Past attempts to stock the Upper Mystic Lake with trout have failed and future efforts have been postponed due to these conditions.

Prevailing water quality standards for the Upper Mystic Lake watershed require minimum dissolved oxygen concentrations of 5.0 mg/l. In the Aberjona River dissolved oxygen standard violations have been observed during previous data collection efforts. Violations usually occur during the summer downstream of the confluence with Sweetwater Brook, a basin with numerous CSOs. In general, however, dissolved oxygen levels are well above standards the remainder of the year. Based on water quality data collected by various state and local

TABLE 1.1

CLASS B WATER QUALITY STANDARDS

Class B - These waters are suitable for bathing and recreational purposes water contact activities, acceptable for public water supply with treatment and disinfection, are an excellent fish and wildlife habitat, have excellent aesthetic values and are suitable for certain agricultural and industrial uses.

Aesthetics	All waters shall be free from pollutants in concentrations or combinations that: a) Settle to form objectionable deposits; b) Float as debris, scum or other matter to form nuisances; c) Produce objectionable odor, color, taste, or turbidity; or d) Result in the dominance of nuisance species.
Dissolved Oxygen	Shall be a minimum of 5.0 mg/l in warm water fisheries and a minimum of 6.0 mg/l in cold water fisheries.
Temperature	Shall not exceed 85°F (28.3°C) in warm water fisheries or 68°F (20°C) in cold water fisheries, nor shall the rise resulting from artificial origin exceed 4.0°F (2.2°C).
pH	Shall be in the range of 6.5 - 8.0 standard units and not more than 0.2 units outside of the naturally occurring range.
Fecal Coliform Bacteria	Shall not exceed a log mean for a set of samples of 200 per 100 ml, nor shall more than 10% of the total samples exceed 400 per 100 ml during any monthly sampling period, except as provided in Regulation 2.1 Shall not exceed the recommended limits of the United States Environmental Protection Agency's National Drinking Water Regulations.

TABLE 1.1

(Cont'd.)

<u>Parameter</u>	<u>Criteria</u>
Tainting Substances	Shall not be in concentrations or combinations that produce undesirable flavors in the edible portions of aquatic organisms.
Color, Turbidity, Total Suspended Solids	Shall not be in concentrations or combinations that would exceed the recommended limits on the most sensitive receiving water use.
Oil and Grease	The water surface shall be free from floating oils, grease and petrochemicals and any concentrations or combinations in the water column or sediments that are aesthetically objectionable or deleterious to the biota are prohibited. For oil and grease of petroleum origin the maximum allowable discharge concentration is 15 mg/l.
Nutrients	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication.
Other Constituents	Waters shall be free from pollutants in concentrations or combinations that; a) Exceed the recommended limits on the most sensitive receiving water use; b) Injure, are toxic to, or produce adverse physiological or behavioral responses in humans or aquatic life; or c) Exceed site-specific safe exposure levels determined by bioassay using sensitive resident species.

agencies from 1970 through 1979, dissolved oxygen levels average about 9 mg/l at the USGS gauge in Winchester. Wet weather data collected more recently as part of this study show all but one composite sample to be above 5 mg/l in dissolved oxygen. Even dissolved oxygen levels in Sweetwater Brook were above Class B standards, averaging about 8 mg/l for the sampling period. Thus, oxygen deficiencies in the Aberjona River do not appear to be a significant water quality problem. Dissolved oxygen levels in the lake, on the other hand, are a persistent problem. In a lake as deep as Upper Mystic Lake, it is common for thermal stratification to occur in the summer months. Algae growing in the warmer epilimnion eventually die and sink to the lake bottom, where they decay.

Oxygen is consumed during the degradation process, which causes oxygen to be eliminated in the hypolimnion, which has no oxygen sources. Anaerobic conditions in the cold hypolimnion have eliminated the cold water fishery potential of the lake.

Biochemical oxygen demand (BOD), is apparently not a serious problem in either the lake or the river. Previous data collection efforts in the 1970's showed BOD levels consistently within the 5 to 30 mg/l range. More recently, wet-weather data collected as part of this study show BOD levels ranging from 1 to 20 mg/l for all sampling locations except the Sweetwater site. CSOs in the Sweetwater basin cause BOD levels to be higher than normal; concentrations averaged 50 mg/l and ranged from 10 mg/l to 189 mg/l. BOD concentrations in the lake average less than 10 mg/l, and are also not a serious problem.

1.3 Objectives of Study

The Upper Mystic Lake (UML) case study is part of the larger Nationwide Urban Runoff Program (NURP). Consequently, the principal goals of this effort are both local and national in scope. The local goals may be expressed as:

1. Identify the characteristics of stormwater runoff in the Upper Mystic Lake Basin;
2. Assess the impacts of this runoff on the water quality conditions of the Upper Mystic Lake;
3. Recommend controls to achieve water quality goals for the Upper Mystic Lake.

The results of this effort will complement the larger national goals through:

4. Contribution to nationwide data base of urban runoff quality for various constituents; and

5. Evaluation of selected management strategies and/or control techniques to address water quality problems in receiving waters.

1.4 Problem Water Quality Constituents

The most important constituents with respect to existing water quality problems in the Upper Mystic Lake are coliform bacteria, the plant nutrients nitrogen and phosphorus, total suspended solids, and heavy metals. The sources of these were investigated during a field data collection program, and were correlated with land use and the rainfall/runoff process during the course of the study. The data necessary to perform the various analyses were collected, and are summarized in Chapter 2.

Coliform organisms are important, because they have been observed in high concentrations in the watershed and bathing beach standards are written for these organisms. Of particular interest is the critical coliform loadings from Sweetwater Brook, where a combined sewer network causes coliform levels in the discharge to approach that of raw sewage.

Nutrients were analyzed because of their direct relation with lake trophic status. Historic and recent water quality data were reviewed to determine the annual loadings of nitrogen and phosphorus to the lake, and to predict the impact of the discharges on the plant growth potential in the lake.

Total suspended solids (TSS) and metals are also included in the analysis. Some metals, particularly zinc and arsenic, appear in high concentrations throughout the watershed, and particularly in the lake sediments.

While other constituents were included in the water quality sampling program, those enumerated above were considered of critical importance and were subject to a more detailed analytical examination.

1.5 Previous Studies and Other Data Sources

Numerous reports and data summaries on water quality in the Mystic watershed are available. Of particular interest are the Water Quality Surveys annually conducted by the MDC for the Mystic River Watershed. Grab samples are taken at a variety of locations in the Aberjona and its tributaries as well as Upper Mystic Lake each year. Constituents usually sampled include dissolved oxygen, BOD, chloride, phosphorus, nitrogen, and coliform.

The USGS has also conducted dye tracer studies in the Aberjona and calculated times of travel for different flows. These data were incorporated into the analysis of the receiving waters to verify the accuracy of the hydraulics of the river as postulated in the model.

USGS flow records at the Aberjona River gauge are available from 1920. These records enable average annual streamflow and runoff coefficients to be calculated.

The Mystic Hydrology Study (CDM, 1981) contains hydraulic information such as channel slopes, roughness coefficients and channel widths which were used in the stream simulations.

The water quality sampling program associated with this study, described in Chapter 2, consisted of flow-weighted composites for those constituents under investigation.

1.6 Products of the Study

One of the outcomes of this analysis is a better understanding of the chemical makeup of urban stormwater runoff. Analysis of runoff data also permitted analysis of first flush and within-storm phenomena. Statistical analyses of constituents provided mean, median, minimum, and maximum concentrations, and aided in establishing pollutant loads for typical storms. Stormwater loads were correlated with land use and the load contribution from different sub-basins was assessed. Critical loading areas were identified.

Once the quantity and quality of urban runoff pollutants was determined, the impact of those discharges on the receiving waters was investigated. Instream conditions were simulated on a long-term basis. Dominant instream biological and physical processes were identified and simulated to determine the water quality conditions that would result from a variety of pollutant loading conditions.

Once the long-term average loadings to the lake were established, the effects of various structural and nonstructural control measures were assessed. Minimum pollutant levels to maintain acceptable water quality conditions in the lake were compared with the capability of the controls to remove pollutants. The physical and economical feasibility of implementing different control strategies must be determined.

Overall, the study has provided a better understanding of the quantitative and qualitative characteristics of local urban runoff, the effects the addition of this stormwater has on the receiving waters including the lake; and finally, what actions can be taken to reduce the quantity or mitigate the effects of urban stormwater to preserve recreational opportunities in Upper Mystic Lake.

1.7 Organization of Report

Chapter 2 presents summaries of available water quality data. The data base is composed of both wet and dry weather samples. Statistical summaries of the data, wet versus dry weather characteristics, and correlations with streamflows are presented. In Chapter 3 the data presented in Chapter 2 are used to estimate loadings of the various pollutants washing off the watershed. A rainfall/runoff model was applied to the basin and the results of the calibration procedure for both the hydrology and water quality components is provided. Chapter 4 describes the receiving water quality analysis. Using results from Chapter 3, a receiving water quality model was used to simulate the effects of urban stormwater loads on the Aberjona River. Long-term pollutant loads to the lake, frequency curves for individual constituents, and relative strengths and locations of pollutant "sinks" are presented. Chapter 5 includes a discussion of problem pollutants and their sources, feasible control strategies to eliminate or mitigate the amount or effects of the problem pollutants, and the feasibility of implementing such control strategies. A series of influence curves, as well as the efficiencies of various control strategies, are provided. Finally, Chapter 6 is a summary of the results of the study and the implications for future water quality conditions.

CHAPTER 2

SYNTHESIS OF FIELD SAMPLING DATA

2.1 Introduction

A field sampling program was conducted as part of the Upper Mystic Lake NURP case study as a means of providing background data for the evaluation of urban runoff and instream water quality and the effect of urban runoff on local receiving water quality. There were two principal objectives of the field program:

1. Identify the quantitative and qualitative characteristics of the local urban runoff, which will be used in the analysis of water quality in the Upper Mystic Lake basin and in the general characterization of urban runoff for possible transfer applications in other areas.
2. Collect the data necessary to evaluate potential control strategies and management practices for alleviating the existing water quality problems.

Both wet and dry weather field samples were collected. Environmental Design and Planning, Inc. (EDP) sampled the Aberjona River during wet weather periods, collecting composite samples representing a number of rainfall events. DEQE staff members and the Mystic River Watershed Association (MRWA), a volunteer organization, collected wet and dry weather grab samples periodically from a number of locations throughout the watershed. The MRWA effort included only eight constituents; DEQE sampled for many more constituents, including some heavy metals. Both sampling efforts provided valuable information concerning water quality characteristics in the Upper Mystic Lake watershed.

Rain gauges were set up in Winchester (police station and public works building), Burlington (Raytheon), and Stoneham (fire station) to measure local rainfall volumes during the sampling period. Hourly rainfall data collected by retired State climatologist Robert Lautzenheiser (Reading) and by the MDC at Spot Pond (Stoneham) were also reviewed to better identify spatial and temporal variations of rainfall for the sampled events. In addition, daily rainfall data were collected by the MRWA as a further check on storm variability.

2.2 Water Quality Characteristics-EDP Data

The event oriented sampling by EDP took place on the following nine dates in 1981:

February 2, 11
April 4, 14
June 20, 22
July 13
August 5, 25

The February sampling consisted of testing of procedures and collection of a limited number of samples. On the remainder of the dates the data necessary to develop event hydrographs and pollutographs were collected at numerous locations. Two types of stations were sampled: end-of-pipe and instream. End-of-pipe (EOP) stations are at points within the stormwater drainage system, and instream stations are in the receiving water.

The EOP's were established to characterize the runoff from small areas of uniform land use. Ideally, the runoff quantity and quality can be correlated with land use for prediction of runoff characteristics for larger areas. The instream stations were used to characterize the runoff for larger areas of mixed land use and to provide the background data for the definition of the important instream reactions and characteristics. Table 2.1 is a list of the stations sampled, and Figure 2.1 displays their locations.

The samples collected were laboratory analyzed for numerous constituents in the following categories: plant nutrients, organics, heavy metals, and bacteria. The plant nutrients, nitrogen and phosphorus, were included to assess the impact of runoff on the eutrophication potential of the lake. Heavy metals are commonly found in urban runoff, and have been found in the watershed. These metals can have an adverse effect on plant and animal livelihood. Total and fecal coliform bacteria are pollution indicators and the data on their concentration were used to predict the effect of urban runoff on water quality at Sandy Beach in the lake. Table 2.2 is a complete listing of the water quality constituents that were quantified.

The normal field sample collection procedure was to form four flow-weighted composite samples from each location during each storm. The purpose of multiple composites is to determine whether the runoff characteristics varied within individual storm events, as occurs with first flush. Coliform bacteria, BOD, and dissolved oxygen analyses were performed on grab samples collected after some of the storm events. The bacteria were sampled from grabs, as that constitutes proper sampling procedure. Since oxygen demanding substances did not appear to be as significant a problem as the plant nutrients and the available budget was limited, they were not included in the detailed pollutograph development, and were quantified from grab sample results.

Table 2.1
SAMPLING STATIONS

<u>Station Location</u>	<u>Abbreviation</u>	<u>Station Type</u>
Hemlock Road	Heml	EOP ¹
Addison Wesley Parking Lot	Addw	EOP
Mishawum Road ²	Mish	Instream
Mill Street ²	Mill	Instream
Washington Street ²	Wash	Instream
Sweetwater Brook	Swat	Instream
Horn Pond Brook	Horn	Instream
USGS Gauge ²	USGS	Instream

¹End-of-pipe

²Aberjona River Station

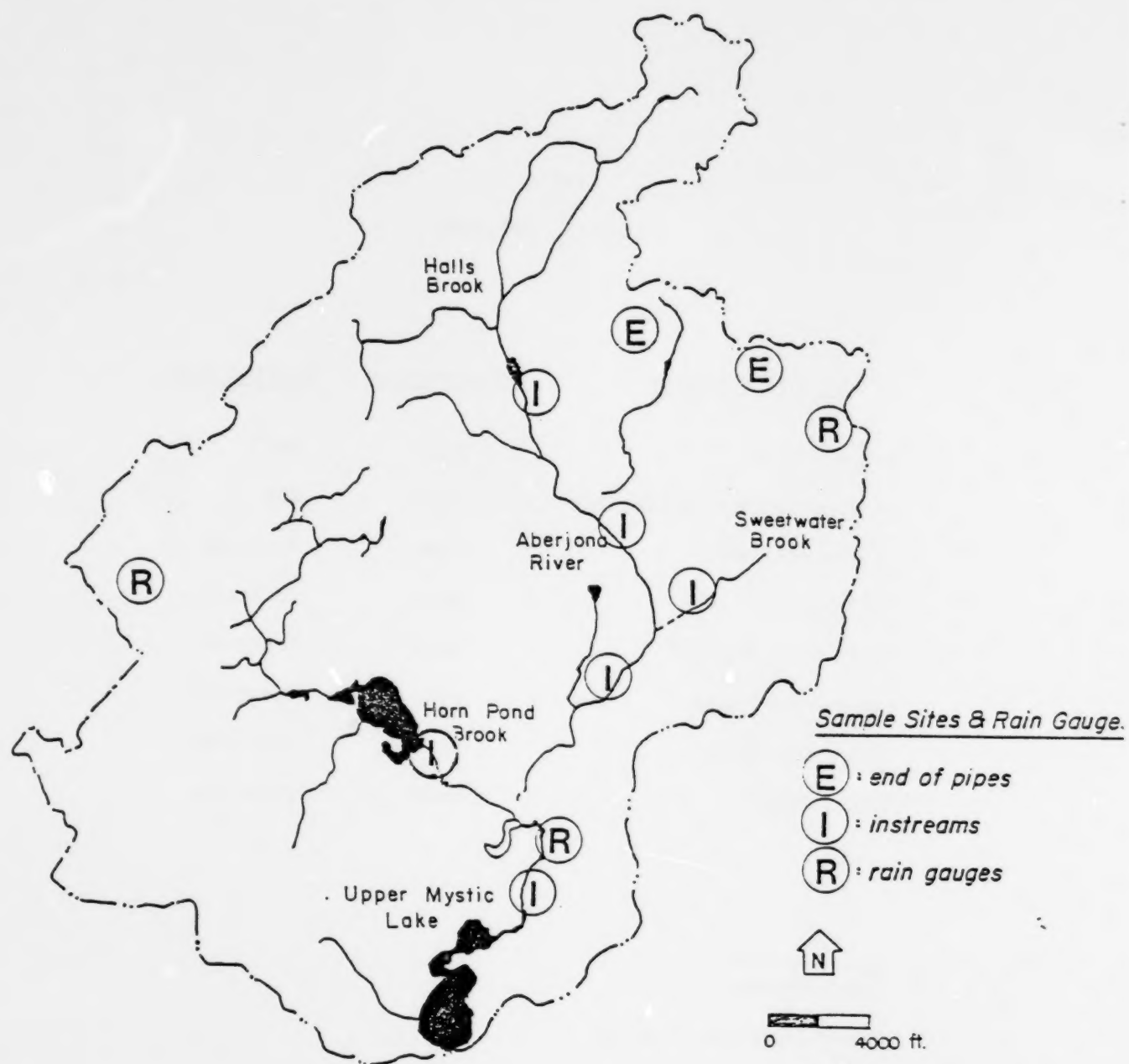


FIGURE 2.1
UPPER MYSTIC LAKE BASIN
--- Basin Boundary

Table 2.2

WATER QUALITY CONSTITUENTS AND ABBREVIATIONS

Biochemical Oxygen Demand (BOD)	Arsenic (As)
Chemical Oxygen Demand (COD)	Aluminum (Al)
Total Suspended Solids (TSS)	Cadmium (Cd)
Volatile Suspended Solids (VSS)	Chromium (Cr)
Total Phosphorus* (PTON, PTOF)	Copper (Cu)
Phosphate Phosphorus* (PO4N, PO4F)	Iron (Fe)
Total Kjeldahl Nitrogen* (TKNN, TKNF)	Lead (Pb)
Ammonia Nitrogen* (NH3N, NH3F)	Manganese (Mn)
Nitrate Nitrogen (NO3N)	Nickel (Ni)
Total Coliform	Tin (Sn)
Fecal Coliform	Zinc (Zn)
Dissolved Oxygen	

* Determined dissolved and total concentrations (N, F at end of abbreviation represents non-filtered and filtered).

After each set of laboratory data became available, they were reviewed and the sampling program altered to reflect the information gathered to date. This practice allowed the program to provide the maximum amount of information about the watershed with the minimum expenditure of resources.

In several instances the data collected during an event were limited, either due to equipment malfunctions or mistakes in sample compositing. The result was a data set that was missing a station altogether or which was insufficient to develop the full storm hydrographs or pollutographs. In those cases, storm total pollutant loads and runoff coefficients were computed using those data that were available.

Runoff coefficients (C) were computed from the rainfall data as the ratio of runoff volume to total rainfall volume. When no significant differences in total precipitation between rainfall gauges were observed, runoff coefficients were based on records at the nearest rainfall gauge. Where significant differences in precipitation volumes were observed between gauges, volumes were averaged proportionally based on proximity of the sampling location to the rain gauges using the Thiessen Weights method.

The Thiessen Method assumes that the amount of rainfall at any station can be applied proportionally to stations by drainage area. Polygons are constructed around each gauge by drawing the perpendicular bisectors of the connecting lines between gauges, as displayed in Figure 2.2. For example, total rainfall for the August 5 storm was 1.42 inches, 1.54 inches, and 0.74 inches at the Winchester, Stoneham, and Burlington gauges. To calculate a rainfall volume for Mishawum Road, the Burlington gauge would be given a 1/3 weighting and the Stoneham gauge a 2/3 weighting because approximately one third of the area draining to Mishawum Road falls within the Burlington "polygon" and the remainder in the Stoneham "polygon". The rainfall value used was $(.33)(.74) + (.67)(1.54)$ or 1.28. The April 4, 14, June 22 and July 13 storms showed little variability in total rainfall, while the remainder showed great variability and the Thiessen Method was required.

The pollutant loads and the runoff coefficients are the principal parameter values computed from the field data. The runoff coefficients are summarized in Table 2.3 and the pollutant loads in Tables 2.4 through 2.10. Heavy metal and priority pollutant data are described separately in Section 2.5. The runoff coefficient values were computed directly from the EDP and the rain gauge data, and reflect the results of individual storm events, including background flow. These low values are the result of flow samples that did not include the entire runoff period. As a result, the runoff volumes computed were only a fraction of the total, which result in low computed runoff coefficients. Therefore, the values in Table 2.3 had to be converted to include the entire runoff period, and also to include the amount of runoff that was not measured because of the increased flow required to activate the automatic samplers. The revised runoff coefficients are also shown in Table 2.3.

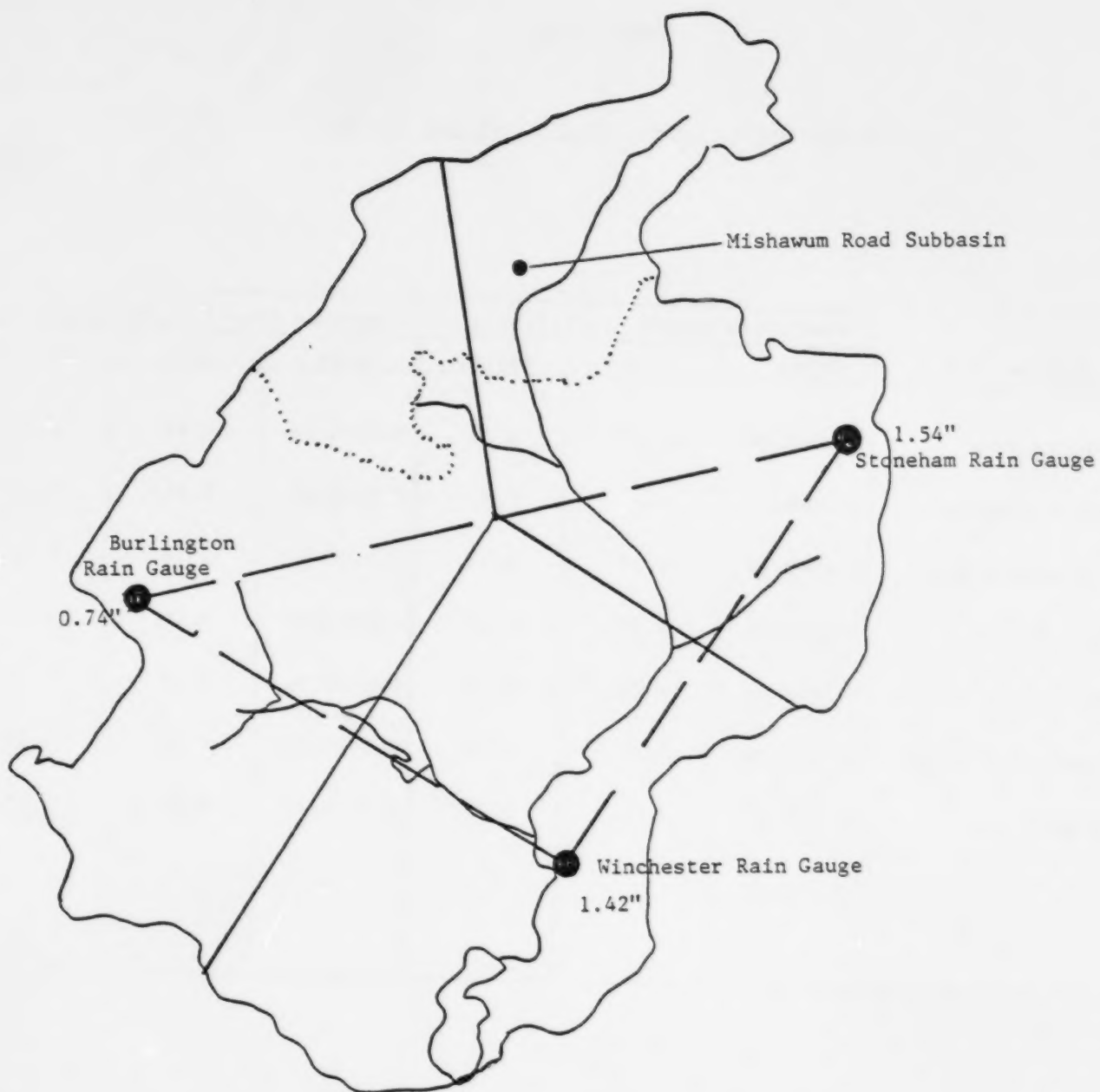


Figure 2.2
Illustration of Thiessen Method
in Upper Mystic Lake Watershed

TABLE 2.3

RUNOFF COEFFICIENTS: UNADJUSTED AND REVISED

Station	Unadjusted Runoff Coefficients ¹			Revised Runoff Coefficients		
	Range	Mean	Median	Range	Mean	Median
Hemlock Road	0.03-0.46	0.27	0.30	0.13-0.76	0.41	0.33
Addison-Wesley	0.09-0.99	0.6	0.6	0.25-0.98	0.64	0.64
Mishawum Road	0.03-0.27	0.17	0.13	0.11-0.49	0.17	0.13
Mill Street	0.02-0.21	0.10	0.14	0.04-0.22	0.14	0.15
Washington Street	0.02-0.14	0.04	0.04	0.04-0.14	0.05	0.04
Sweetwater Brook	0.10-0.50	0.21	0.20	0.16-0.50	0.21	0.20
Gauge	0.02-0.23	0.11	0.11	0.02-0.23	0.11	0.11

Table 2.4

WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR HEMLOCK ROAD
(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	8 - 40	17	9	0.7 - 47	9.8	4.3
TSS	9 - 1143	348	295.8	7 - 2249	508	62.5
VSS	10 - 487	249	249	3.5 - 958	481	41.0
PTON	0.18 - 8.24	2.2	0.46	0.08 - 16.2	3.5	0.3
PTOF	0.07 - 5.88	1.5	0.21	0.05 - 11.5	2.4	0.2
PO4N	0.09 - 3.68	1.0	0.33	0.06 - 7.2	1.6	0.2
PO4P	0.07 - 3.59	1.0	0.18	0.05 - 7.1	1.5	0.1
NO3N	3.2 - 56.2	17.0	4.2	1.5 - 110.6	29.5	2.9
NH3N	0.35 - 12.0	3.5	0.8	0.2 - 24	6.3	0.4
NH3P	0.16 - 8.0	2.3	0.6	0.02 - 16	4.1	0.25
TKNN	4.0 - 124.0	40.8	16.82	3.1 - 224	68.3	13.0
TKNP	1.9 - 56.1	25.5	22.0	1.25 - 110	31.7	7.8

Table 2.5

WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR ADDISON WESLEY

(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	2.3 - 11.1	5.5	4.4	1.0 - 8.9	4.6	4.2
TSS	6.3 - 121	63.9	63	19.5 - 79.2	45.5	30
VSS	1.78 - 20.3	8.7	4.1	5.5 - 13.3	9.0	8.3
PTON	0.022 - 0.15	0.11	0.1	0.03 - 0.1	0.1	0.1
PTOF	0.017 - 0.17	0.075	0.061	0.015 - 0.1	0.06	0.07
P04N	0.017 - 0.093	0.055	0.057	0.02 - 0.06	0.05	0.05
P04F	0.011 - 0.015	0.05	0.023	0.015 - 0.07	0.04	0.03
N03N	0.39 - 2.5	1.47	1.41	0.1 - 1.4	1.1	1.2
NH3N	0.2 - 1.14	0.47	0.37	0.03 - 0.7	0.37	0.4
NH3F	0.13 - 0.97	0.39	0.33	0.02 - 0.5	0.29	0.3
TKNN	0.5 - 7.42	2.92	2.7	1.0 - 3.5	2.0	1.8
TKNF	0.35 - 2.57	1.16	0.85	0.8 - 1.2	1.0	1.1

TABLE 2.6

WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR MISHAWUM ROAD

(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	212 - 1920	865	800	0.4 - 37.0	8.9	7.4
TSS	1259 - 9154	3667	2215	14 - 53.4	33.1	30
VSS	431 - 2728	1159	910	4.8 - 17.6	11.1	11.1
PTON	2.9 - 75.2	17.5	7.9	0.03 - 0.4	0.15	0.09
PTOF	1.0 - 3.2	3.5	2.2	0.01 - 0.06	0.03	0.02
PO4N	1.9 - 6.9	4.6	4.7	0.02 - 0.1	0.05	0.04
PO4F	0.56 - 4.25	1.7	1.5	0.006 - 0.02	0.015	0.015
NO3N	103 - 305	201	207	1.3 - 3.2	2.0	1.8
NH3N	262 - 791	436	373	2.1 - 6.5	4.5	4.3
NH3F	248 - 766	419	366	2.0 - 6.3	4.3	4.2
TKNN	415 - 6065	1340	541	3.8 - 67.7	14.5	6.4
TKNF	385 - 5949	1641	563	3.2 - 66.3	17.3	5.8

TABLE 2.7

WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR MILL STREET
(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	117 - 415	303	337	1.3 - 19.8	6.3	5.1
TSS	790 - 17,318	8,136	7,633	7.2 - 28.5	12.8	10.0
VSS	518 - 5,182	3,211	3,483	3.1 - 10.8	5.9	5.2
PTON	7.2 - 67.3	33.7	33.9	0.08 - 0.15	0.11	0.1
PTOF	6.1 - 43.2	16.1	10.8	0.01 - 0.09	0.04	0.025
PO4N	7.5 - 36.9	18.7	21.8	0.008 - 0.08	0.04	0.02
PO4F	1.8 - 11.2	5.8	6.0	0.008 - 0.05	0.02	0.02
NO3N	53.3 - 230	102	76.9	1.5 - 3.1	2.1	1.9
NH3N	9.2 - 76.3	36.0	32.1	2.6 - 8.5	4.8	4.3
NH3F	3.7 - 54.8	24.7	22.8	2.5 - 8.3	4.5	4.0
TKNN	121.5 - 461	225	158	3.6 - 96.2	18.3	5.3
TKNF	38.5 - 134	83.8	76.2	3.2 - 90.4	21.7	4.8

TABLE 2.8

WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR WASHINGTON STREET
(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	588 - 1,638	1,096	1,180	2.2 - 46.0	11.0	8.7
TSS	121 - 27,620	10,779	1,992	17 - 272	117	62
VSS	20.3 - 11,717	4,001	949	9.7 - 107	44	23
PTON	0.04 - 77.7	25.6	19.6	0.08 - 0.7	0.3	0.3
PTOF	0.023 - 40.9	10.4	4.3	0.02 - 0.4	0.1	0.05
PO4N	0.093 - 26.8	7.7	4.5	0.04 - 0.16	0.09	0.06
PO4F	0.023 - 1.8	1.3	1.6	0.01 - 0.02	0.017	0.02
NO3N	1.41 - 431	179	151	1.3 - 3.6	2.2	2.1
NH3N	0.37 - 862	231	142	1.0 - 7.2	3.1	2.2
NH3F	0.33 - 845	220	139	0.9 - 7.0	3.0	2.2
TKNN	2.7 - 1,174	483	243	1.3 - 84.4	16.9	5.2
TKNF	1.2 - 956	312	174	1.2 - 79.3	16.1	4.8

TABLE 2.9
WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR USGS GAUGE
(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	516 - 2,460	1,547	977	2.9 - 13.0	7.3	5.7
TSS	666 - 14,331	4,010	1,360	7.4 - 16.8	13.2	13.2
VSS	586 - 4,928	1,852	947	3.4 - 5.8	6.3	5.1
PTON	6.1 - 37.0	19.3	25.0	0.04 - 0.2	0.1	0.1
PTOF	3.2 - 12.1	7.0	5.4	0.014 - 0.05	0.04	0.03
PO4N	2.5 - 23.6	10.7	5.8	0.03 - 0.07	0.05	0.04
PO4F	1.8 - 8.0	4.3	3.0	0.009 - 0.02	0.02	0.02
NO3N	208 - 1,755	688	390	2.1 - 3.5	2.9	3.0
NH3N	164 - 2,679	713	234	0.5 - 5.6	2.7	2.8
NH3F	124 - 2,559	662	206	0.4 - 5.4	2.4	2.1
TKNN	305 - 4,160	1,085	444	1.2 - 6.7	3.8	3.5
TKNF	235 - 3,217	1,155	590	0.9 - 6.4	3.4	3.2

TABLE 2.10

WATER QUALITY CONSTITUENT LOAD AND CONCENTRATION SUMMARY
FOR SWEETWATER BROOK

(constituent abbreviations in Table 2.11)

Constituent	Load (lbs/storm)			Average Concentration (mg/l)		
	Range	Mean	Median	Range	Mean	Median
BOD	293 - 3,039	1,017	815	2.2 - 189	17.3	5.5
TSS	150 - 3,567	1,117	538	29.2 - 305	167	188
VSS	133 - 1,349	432	178	18.8 - 185	76	79
PTON	1.8 - 18.7	8.3	4.9	0.3 - 1.5	0.7	0.6
PTOF	0.9 - 10.6	3.2	1.8	0.1 - 0.8	0.3	0.2
P04N	0.35 - 6.4	2.5	2.0	0.1 - 0.8	0.4	0.4
P04F	0.4 - 3.2	1.5	1.25	0.07 - 1.0	0.3	0.1
NO3N	29.5 - 505	167	94	1.1 - 2.9	2.0	1.8
NH3N	99 - 1,389	385	168	0.2 - 1.2	0.8	0.4
NH3F	90 - 1,282	361	160	0.1 - 1.8	0.5	0.4
TKNN	119 - 1,448	451	260	1.7 - 10.6	5.1	4.1
TKNF	124 - 1,355	515	483	0.9 - 2.8	1.7	1.5

Flow samples at Hemlock Road, Addison-Wesley, Mishawum Road, and Sweetwater Brook effectively captured entire runoff events at each location. Continuous flow records at the gauge were also available. However, for the remaining instream locations, where flow sampling was discontinued before the runoff event was completed, improved runoff coefficients were back-calculated based on drainage area and runoff volumes at those locations where complete hydrographs were available. For example, for the July 13 storm, sampling at the Washington Street site was discontinued 20 hours after the storm began. During that period, 102,900 cubic feet of water ran off. Concurrently, at the gauge, 112,200 cubic feet of water had run off during the 20-hour period. However, gauge flow records show that the runoff event continued for another 9 hours, and eventually 145,100 cubic feet passed the gauge. The final volume represented a 30 percent increase over what was measured at the gauge for the 20-hour period. Consequently, the runoff volume measured at Washington Street was increased by 30%, from 102,900 to 133,800 cubic feet and the initial runoff coefficient was revised upwards.

2.3 Water Quality Characteristics - MRWA and DEQE Grab Sample Data

Members of the Mystic River Watershed Association (MRWA) collected water samples from two locations (Mishawum Road and the USGS gauge) in the Aberjona River between November 20, 1980 and August 1, 1981. Samples were collected up to three times each week, and often twice on a sampling date. DEQE Staff members also collected samples from a number of locations in the watershed on a random basis. These locations are listed in Table 2.11.

A number of rain gauges were also set up to measure local rainfall quantities over the sampling period. The rainfall data were used primarily to define the spatial variation of local rainfall over the watershed and the relationships between local rainfall and that at the Logan Airport and Spot Pond gauges. Since some of the storms sampled by EDP as part of the NURP study were summer thunderstorms, the intensity and the duration of rainfall tended to vary significantly over the basin. The MRWA gauges provided additional components of a network from which spatial variations could be better determined and used to compute local urban runoff characteristics.

The instream data were collected as a means of characterizing the local water quality under a variety of instream and meteorologic conditions. They were used as a measure of the quality of the background flow and of the baseflow in the basin. Background flow is that added upstream of Mishawum Road, and baseflow is the flow added naturally along the course of the stream during both dry and wet weather. The results are used as input to the water quality computations being made for the basin. The DEQE data were used to determine local baseflow and runoff quality.

Table 2.11
DEQE Sampling Stations

<u>Station</u>	<u>Location</u>
<u>Upper Mystic Lake:</u>	
Sandy Beach	Winchester
West Shore Inlet	Winchester
Lake Outlet	Medford/Arlington
Yacht Club Inlet	Winchester
Aberjona River Inlet	Winchester
 <u>Aberjona River:</u>	
Olympia Ave.	Woburn
Washington Street	Winchester
USGS Gauge	Winchester
Mishawum Road	Woburn
Salem Street	Woburn
Mill Street	Woburn
 <u>Tributaries</u>	
Sweetwater Brook	Stoneham
Holiday Inn Culvert	Woburn
Holiday Inn Stream	Woburn
Ditch #2	Wilmington
Horn Pond	Woburn
Hemlock Ave.	Reading
Unnamed Tributary	Winchester

The MRWA water quality samples were analyzed for COD; ammonia, nitrate, and total Kjeldahl nitrogen; phosphates; oil and grease; and total and suspended solids. The results at each station were divided into two groups, wet weather and dry weather. The differentiation was based on rainfall. Samples collected on the day of a rainfall event at Mishawum Road, or within two days after a rainfall event at the USGS gauge were considered wet weather samples. Because of the time lag between the end of the rainfall event and the end of the runoff event at the gauge, it was necessary to consider antecedent conditions 48 hours prior to the time the sample was taken. Water quality data were analyzed in total and then separately as wet and dry weather. Table 2.12 is a summary of these data and the results of some simple statistical analyses.

The DEQE water quality samples were analyzed for: COD, BOD, pH, suspended and volatile suspended solids, total phosphorus, orthophosphate, ammonia, nitrite, nitrate, TKN, total and fecal coliform, and the heavy metals (aluminum, arsenic, copper, iron, manganese, zinc, lead, tin, nickel, cadmium, and chromium). Aberjona River samples were taken at Olympia Avenue, Washington Street, Mishawum Road, Mill Street, the USGS gauge, and Salem Street during the period April 7, 1981 through September 17, 1981. Lake samples and tributary samples were also taken at different locations as presented in Table 2.11. Table 2.13 is a summary of these data and the results of simple statistical analyses for two stations that had the most data points, and were not included in the MRWA sampling effort. Statistical analyses for the remaining DEQE stations are presented in Appendix A.

2.4 Wet Versus Dry Weather Characteristics

The results displayed in Table 2.12 indicate that there is no significant difference between wet weather and dry weather concentrations of the sampled constituents at either station. The mean, median, and standard deviation values are remarkably close for wet weather, dry weather, and all samples taken together. This result indicates that the stormwater runoff quality is not significantly different from that of the baseflow.

The water quality data were further analyzed for relationships between the two stations, between water quality and streamflow, and with data collected by EDP. No significant correlation exists between the quality at the two stations in terms of the constituents in Table 2.12. An attempt was made to correlate the data using several different relationships, which include a provision for time of travel between the stations, but none provided a good general representation. While the quality at Mishawum Road may be related to that at the USGS gauge, it is not possible to represent that relationship using simple equations relating the constituents listed in Table 2.12.

A similar analysis was performed in correlating quality at the two stations with streamflow. Regression analyses were used to develop relationships between the concentrations of the water quality

Table 2.12

SUMMARY OF HRWA WATER QUALITY DATA

USGS GAUGE

Constituents	No. of Samples			Median Conc. (mg/l)		Mean Conc. (mg/l)		Std. Dev. (mg/l)		Range (mg/l)					
										Min.		Max.			
	Dry	Wet	D&W	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	D&W
COD	22	9	31	44	40	43.64	40.9	42.84	11.52	9.75	26.0	31.0	61.0	69.0	69.0
NH ₃ -N	78	33	111	5.4	5.2	5.52	5.85	5.78	4.38	2.81	1.20	0.76	0.76	14.0	18.0
NO ₃ -N	61	30	91	1.6	1.6	1.59	1.51	1.56	0.53	0.54	0.60	0.70	0.60	3.30	3.30
TKN	61	31	92	5.1	4.5	5.49	5.34	5.44	2.34	2.61	1.50	1.50	16.0	10.0	16.0
TOTAL PO ₄ -P	78	35	113	0.07	0.07	0.072	0.075	0.073	0.032	0.025	0.04	0.04	0.17	0.18	0.18
TOTAL SOLIDS	75	39	114	320.	270.	315.	286.	305.	85.9	70.7	48.	136.	538.	460.	538.
TSS	77	30	107	3.5	5	3.87	6.12	4.50	8.32	3.03	0.0	0.0	14.	46.	46.
OIL & GREASE	14	6	20	0.3	0.4	0.71	0.33	0.6	0.3	0.6	0.0	0.0	1.8	0.8	1.8

MISHAMUTH ROAD

Constituents	No. of Samples			Median Conc. (mg/l)		Mean Conc. (mg/l)		Std. Dev. (mg/l)		Range (mg/l)					
										Min.		Max.			
	Dry	Wet	D&W	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	D&W
COD	27	4	31	45	37.5	46.1	39.5	45.3	9.11	13.5	25.0	31.0	78.0	52.0	78.
NH ₃ -N	76	39	115	8.3	7.0	9.16	8.43	8.91	5.69	5.98	3.1	1.6	35.8	28.0	37.
NO ₃ -N	58	35	93	1.3	1.2	1.42	1.31	1.38	0.75	0.59	0.1	0.0	3.4	3.9	3.9
TKN	61	35	96	8.25	8.3	8.36	8.41	8.38	5.29	2.90	1.1	2.0	15.0	26.0	26.
TOTAL PO ₄ -P	78	41	119	0.06	0.06	0.065	0.066	0.065	0.029	0.057	0.0	0.0	0.48	0.14	0.48
TOTAL SOLIDS	72	39	111	330.	308.	404.	359.	388.	405.	378.	180.	58.	2272.	2740.	2740.
TSS	74	40	114	7.	6.	10.62	9.25	10.14	11.2	13.09	0.0	0.0	60.	47.	60.
OIL & GREASE	14	4	18	0.35	0.35	0.46	0.63	0.5	0.5	0.25	0.0	0.1	1.8	1.8	1.8

TABLE 2.13

PARTIAL SUMMARY OF DEQE WATER QUALITY DATA

Constituent	Median Conc. (mg/l)			Median Conc. (mg/l)			Minimum Conc. (mg/l)			Maximum Conc. (mg/l)		
	Dry	Wet	W&D	Dry	Wet	W&D	Dry	Wet	W&D	Dry	Wet	W&D
Total P BOD TKN NO ₃ PO ₄ TSS	O L Y M P I A A V E N U E											
	0.035	0.6	0.02	0.03	0.6	0.04	0.03	0.6	0.03	0.04	0.6	0.6
	2.1	0.9	0.9	1.7	0.9	1.5	0.9	0.9	0.9	2.1	0.9	2.1
	0.17	0.23	0.17	0.24	0.23	0.23	0.15	0.23	0.15	0.41	0.23	0.41
	1.6	3.0	1.6	1.6	3.0	1.9	1.4	3.0	1.4	1.7	3.0	3.0
	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.20	0.03	0.02	0.03
Total P BOD TKN NO ₃ PO ₄ TSS	S A L E M S T R E E T											
	0.04	-	-	0.05	-	-	0.04	-	-	0.06	-	-
	1.5	-	-	1.9	-	-	1.5	-	-	2.7	-	-
	0.58	-	-	0.57	-	-	0.49	-	-	0.63	-	-
	1.0	-	-	1.4	-	-	0.5	-	-	1.3	-	-
	0.03	-	-	0.03	-	-	0.02	-	-	0.03	-	-
Total P BOD TKN NO ₃ PO ₄ TSS	4	-	-	5.7	-	-	3.5	-	-	9.5	-	-

constituents and the streamflow. Table 2.14 is a summary of the results of the analyses at the USGS station. The results presented are the correlation coefficients for regressions of flow on the day of the sample versus water quality concentration. Correlation coefficients have two important attributes: their sign and magnitude. The sign indicates whether the two values are positively or negatively correlated. Positive correlation means that the concentration increases with flow, while negative correlation indicates that the concentration decreases with increasing flow. The magnitude of the coefficient relates how well the flow and constituent concentrations are correlated. A value of 1.0 (or -1.0) reflects perfect correlation, while 0.0 indicates perfect non-correlation. Values between 0.0 and 1.0 (or -1.0) indicate the relative degree of correlation.

The results in Table 2.14 show that of all the constituents measured at the USGS gauge, nitrate and ammonia nitrogen are best correlated with streamflow, although the correlations are not particularly strong. Because the number of samples is significant, we conclude that none of the constituents are strongly correlated with streamflow. These results are indicative of the variable nature of the quality of baseflow and urban runoff inflow.

The final analysis performed with data was a comparison with stormwater sampling data collected by EDP. The comparison consisted of a desktop review of two sources, which resulted in the conclusion that the grab sample data are clearly indicative of instream conditions. The two data sources compare very well. This analysis served as a type of validation of both sources.

The poor correlations between the quality at the two stations and between quality and streamflow do not indicate poor data or failure of the program. It simply establishes that such relationships do not exist, which is not uncommon in such complex, urbanized areas.

The data collected by MRWA and DEQE do provide a good characterization of the dry and wet weather water quality at the two locations in the Aberjona in particular and at the various other locations in the watershed. These data were essential to accurately simulate the water quality processes in the receiving waters as part of the determination of pollutant loads to the Upper Mystic Lake.

2.5 Heavy Metals and Priority Pollutant Data

A limited number of the stormwater samples were analyzed for heavy metals and organic priority pollutants. Each sample was a storm composite. Metals analyzed in the sampling effort included:

Aluminum (Al)	Copper (Cu)
Zinc (Zn)	Lead (Pb)
Nickel (Ni)	Iron (Fe)
Manganese (Mn)	Arsenic (As)

Table 2.14

RESULTS OF FLOW CORRELATION ANALYSIS
FOR THE USGS GAUGE DATA

<u>Constituent</u>	<u>Correlation Coefficient</u>
COD	-0.40
Total Phosphorus	0.05
Oil and Grease	0.15
Nitrate - N	-0.66
Ammonia - N	-0.67
TKN	-0.43
Total Solids	-0.49
Total Suspended Solids	0.29

Tin (Sn)
Cadmium (Cd)

Chromium (Cr)

Table 2.15 presents mass loads for heavy metals for each of the storms. Table 2.16 presents the same data on a pound per acre basis. Tables 2.17 through 2.23 present statistical summaries for loads and concentrations. Wet weather average concentrations for data collected by EDP compare favorably with wet weather concentrations collected by DEQE Staff. However, dry weather metal concentrations are, in general, an order of magnitude lower than wet weather concentrations. For example, at Mishawum Road, wet weather aluminum concentrations range from 1.0 to 3.0 mg/l, while dry weather samples approach 0.1 mg/l. Similarly, wet weather zinc concentrations at Sweetwater Brook range from 0.2 to 0.6 mg/l, while dry weather zinc concentrations are closer to 0.02 mg/l.

It is not uncommon for dry weather metal concentrations to be lower than wet weather concentrations. Runoff is the principal source of heavy metals in many urban areas. Baseflow from groundwater sources is characterized by much lower concentrations, as the metals adsorb to soil particles when water percolates into the ground, effectively removing most metals from surface infiltration before it reaches the water table.

Samples collected at the Addison-Wesley and Hemlock Avenue end-of-pipe sampling stations during two storms were analyzed for organic priority pollutants. None of the constituents were found in the samples. The raw water data are presented in Appendix A.

2.6 Stormwater Quality Characteristics

2.6.1 Occurrence of First Flush

The wet weather data were reviewed to determine whether a first flush occurs. Data from the end-of-pipe stations and the Mishawum Road, Washington Street, and gauge sampling sites were used. Average concentrations of TSS, phosphorus, TKN, phosphate, ammonia, and nitrate were plotted against the percentage of total storm runoff that occurred up to the time the composite(s) were taken. The purpose of this exercise was to determine whether concentrations decreased as storms progressed. A storm that exhibited initially high concentrations that continually decreased as the storm progressed was considered as exhibiting first flush effects. Data from every storm could not be included in the analysis, however, because some water quality samples were composited over too large a portion of the storm. In some cases, individual composites represented over 90 percent of storm runoff. Thus, whatever first flush effects may have occurred would be lost in the compositing. This was especially true at Sweetwater Brook and Addison-Wesley, where samples taken even half-hourly sometimes failed to adequately capture hydrograph

TABLE 2.15 Loads by Storm for Metals (lbs)

		Loads (lbs.)										
STATION	DATE	Al	Cu	Zn	Pb	Ni	Fe	Mn	As	Sn	Cr	Cd
Mishawum	6-20-81	114.4	528.0	24.6	5.3	1.8	404.8	58.1	2.8	0.0	—	0.0
	6-22-81	200.7	32.8	191.5	5.5	4.6	291.8	18.2	0.82	0.91	—	0.91
	7-13-81	65.2	19.9	8.9	4.8	—	157.9	31.6	0.34	0.41	—	—
	8-05-81	53.3	17.1	6.15	2.05	2.05	164.0	30.1	3.07	0.41	0.0	—
	8-24-81	56.7	24.2	11.8	5.2	—	159.8	31.4	—	0.15	—	—
Mill St.	6-20-81	81.4	375.6	17.5	3.8	1.3	288.0	41.3	2.0	0.0	—	0.0
	6-22-81	375.1	50.0	212.5	31.2	25.0	1688.0	218.8	7.5	18.8	—	0.0
	7-13-81	11.2	1.6	2.2	6.4	—	44.2	14.3	—	0.1	—	—
	8-05-81	31.7	—	3.3	—	—	76.8	—	—	0.0	—	—
	8-24-81	9.2	0.8	2.2	—	—	—	—	—	—	—	—
Sweet-water	6-20-81	35.9	2.8	7.1	9.0	0.5	80.2	7.1	0.14	0.0	—	0.0
	6-22-81	482.6	10.2	34.6	35.2	3.4	851.7	21.0	0.0	1.7	—	0.0
	7-13-81	41.9	1.4	5.1	3.5	—	74.4	5.6	—	.02	—	—
	8-05-81	56.4	—	14.9	—	—	427.8	—	—	—	—	—
	8-24-81	47.0	23.5	8.1	—	—	—	—	—	—	—	—
Washington	6-20-81	253.2	15.4	59.4	30.8	1.1	495.4	67.2	2.5	0.0	—	0.0
	6-22-81	662.9	15.9	51.3	44.2	0.0	1149.0	55.7	1.6	35.4	—	0.0
	7-13-81	33.9	5.7	9.9	2.8	—	103.5	26.4	—	0.09	—	—
	8-05-81	500.3	14.3	25.5	24.5	1.0	612.5	54.1	—	1.12	2.0	0.0
	8-24-81	70.8	4.4	8.1	6.7	—	104.5	17.9	—	1.5	—	—
USGS Gauge	7-13-81	12.4	12.5	3.2	2.2	—	32.8	10.7	0.18	0.06	—	—
	8-05-81	269.9	44.3	29.3	22.2	0.0	468.8	582.1	35.1	1.0	0.0	0.0
	8-24-81	20.9	5.9	5.0	4.4	—	38.7	11.0	—	0.1	—	—
Hemlock	6-20-81	3.6	0.4	0.3	0.4	0.04	3.8	1.2	0.006	0.0	—	0.0
	6-22-81	0.4	0.04	0.4	0.04	0.08	0.4	0.16	0.0	0.013	—	0.013
	7-13-81	2.3	0.2	0.16	0.22	—	3.3	0.59	0.021	0.001	—	—
	8-05-81	0.7	0.06	0.06	0.09	0.012	0.9	0.19	0.005	0.03	0.005	0.0
Addison-Wesley	6-22-81	1.8	0.3	3.5	0.15	0.08	1.7	0.08	0.0	0.15	—	0.0
	7-13-81	5.4	0.2	0.2	0.4	—	7.5	0.4	0.015	0.10	—	0.0
	8-05-81	0.13	.008	.014	.017	.002	0.17	.002	.0005	.002	.0008	0.0

TABLE 2.16 Loads by Storm for Metals (lb/acre)

STATION	DATE	Loads (lb/acre)										
		Al	Cu	Zn	Pb	Ni	Fe	Mn	As	Sn	Cr	Cd
Hishawua	6-20-81	.028	.131	.006	.001	.0004	.100	.014	.0007	0.0	—	0.0
	6-22-81	.050	.008	.048	.001	.001	.073	.005	.0002	.0002	—	.0002
	7-13-81	.016	.005	.002	.001	—	.039	.008	.0001	.0001	—	—
	8-05-81	.013	.004	.002	.0005	.0005	.041	.007	.0008	.0001	0.0	0.0
Mill St.	8-24-81	.014	.006	.003	.001	—	.040	.008	—	.0001	—	—
	6-20-81	.013	.060	.003	.0006	.0002	.046	.007	.0003	0.0	—	0.0
	6-22-81	.059	.008	.034	.005	.004	.286	.035	.001	.003	—	0.0
	7-13-81	.002	.0003	.0003	.001	—	.007	.002	—	.0001	—	—
Sweet-water	8-05-81	.005	—	.0005	—	—	.012	—	—	0.0	—	—
	8-24-81	.001	.0001	.0003	—	—	—	—	—	—	—	—
	6-20-81	.025	.002	.005	.006	.0003	.055	.005	.0001	0.0	—	0.0
	6-22-81	.333	.007	.024	.024	.002	.587	.014	0.0	.001	—	0.0
Washington	7-13-81	.029	.001	.004	.002	—	.051	.004	—	.0001	—	—
	8-05-81	.039	—	.010	—	—	.295	—	—	—	—	—
	8-24-81	.032	.016	.006	—	—	—	—	—	—	—	—
	6-20-81	.030	.002	.007	.004	.0001	.059	.008	.0003	0.0	—	0.0
USGS Gauge	6-22-81	.078	.002	.006	.005	0.0	.136	.007	.0002	.004	—	0.0
	7-13-81	.004	.0007	.001	.0003	—	.012	.003	—	.00001	—	—
	8-05-81	.059	.002	.003	.003	.0001	.072	.006	—	.0001	.0002	0.0
	8-24-81	.008	.0005	.001	.0008	—	.012	.002	—	.0001	—	—
Hemlock	7-13-81	.0008	.0008	.0002	.0001	—	.002	.0007	.00001	0.0	—	—
	8-05-81	.017	.003	.002	.001	0.0	.029	.036	.002	.0001	0.0	0.0
	8-24-81	.001	.0004	.0003	.0003	—	.002	.0007	—	0.0	—	—
	6-20-81	.072	.008	.006	.008	.0008	.076	.024	.0001	0.0	—	0.0
Addison-Wesley	6-22-81	.008	.0008	.008	.0008	.0016	.008	.0032	0.0	.0003	—	.0003
	7-13-81	.046	.004	.0032	.0044	—	.066	.012	.0004	.00002	—	—
	8-05-81	.014	.001	.0012	.0018	.0002	.018	.004	.0001	.0006	.0001	0.0
	6-22-81	0.1	.017	.194	.008	.004	.094	.004	0.0	.008	—	0.0
Wesley	7-13-81	0.3	.011	.011	.022	—	.412	.02	.0008	.006	—	—
	8-05-81	.007	.0004	.0008	.0009	.0001	.009	.0001	.00003	.0001	.00004	0.0

TABLE 2.17
Metals Load and Concentration Summary

For Hemlock Road

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	0.4 - 3.6	1.7	1.5	.3 - 1.8	1.35	1.65
Cu	0.04 - 0.4	0.18	0.13	.03 - .17	.132	.165
Zn	0.06 - 0.4	0.23	0.23	.13 - .27	.175	.15
Pb	0.04 - 0.4	0.19	0.16	.03 - .23	.155	.18
Ni	.012 - .08	.04	.04	.02 - .06	.037	.03
Fe	0.04 - 3.8	2.1	2.1	.3 - 2.6	1.7	1.95
Mn	0.16 - 1.2	0.54	0.39	.12 - .54	.398	.465
As	0 - .021	.008	.006	0 - .017	.008	.0075
Sn	0 - .03	.011	.007	0 - .076	.022	.0055
Cr	.005 - .005	.005	.005	.012 - .012	.012	.012
Cd	0 - .013	.004	0	0 - 0.1	.003	0

TABLE 2.18

Metals Load and Concentration Summary

For Addison - Wesley

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	0.13 - 5.4	2.4	1.8	1.2 - 2.8	1.9	1.7
Cu	.008 - .3	.17	0.2	.1 - .22	.143	.11
Zn	.014 - 3.5	1.2	0.2	.1 - 2.3	.863	.19
Pb	.017 - .4	.19	.15	.1 - 2.3	.177	.2
Ni	.002 - .08	.04	.04	.02 - .05	.035	.035
Fe	.17 - 7.5	3.1	1.7	1.1 - 3.9	2.43	2.3
Mn	.002 - .4	.16	.08	.05 - .25	.17	.21
As	0 - .015	.005	.0005	0 - .008	.005	.007
Sn	.002 - .15	.084	.1	.028 - .07	.05	.053
Cr	.0008 - .0008	.0008	.0008	.01 - .01	.01	.01
Cd	0.0 - 0.0	0.0	0.0	0 - 0	0	0

TABLE 2.19

Metals Load and Concentration Summary

For Mishawum

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	53.3 - 200.7	98.1	65.2	.65 - 2.2	1.14	0.95
Cu	17.1 - 528	124.4	24.2	.25 - 3.0	0.87	0.36
Zn	6.15 - 191.5	48.6	11.8	.09 - 2.1	0.54	0.14
Pb	2.05 - 5.5	4.6	5.2	.03 - 0.1	0.058	0.06
Ni	1.8 - 4.6	2.8	2.0	.01 - .05	0.03	0.03
Fe	157.9 - 404.8	235.7	164.0	2.3 - 3.2	2.66	2.4
Mn	18.2 - 58.1	33.9	31.4	0.2 - 0.61	0.408	0.44
As	0.34 - 3.07	1.8	1.8	.005 - 0.45	0.01875	0.012
Sn	0.0 - 0.91	0.4	0.4	0 - .01	.005	0.006
Cr	0.0 - 0.0	0.0	0.0	0 - 0	0	0.00
Cd	0.0 - 0.91	0.3	0.0	0 - .01	.003	0.00

TABLE 2.20

Metals Load and Concentration Summary

For Mill Street

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	9.2 - 375.1	101.7	31.7	.38 - .95	.642	0.6
Cu	0.8 - 375.6	107.0	25.8	.05 - .08	.067	0.07
Zn	2.2 - 212.5	58.9	10.4	.10 - .34	.17	0.13
Pb	3.8 - 31.2	13.8	6.4	.05 - .32	.14	0.05
Ni	1.3 - 25.0	13.2	13.2	.01 - .04	.025	0.025
Fe	44.2 - 1688.0	524.2	182.4	1.8 - 2.7	2.25	2.25
Mn	14.3 - 2.8.8	91.5	41.3	0.3 - .71	.45	0.35
As	2.0 - 7.5	4.8	4.8	.012 - .012	0.012	0.012
Sn	0.0 - 18.8	4.7	0.05	0 - .03	.012	0.005
Cr	-	-	-	-	-	-
Cd	0.0 - 0.0	0.0	0.0	0 - 0	0	0

TABLE 2.21
Metals Load and Concentration Summary
For Washington

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	33.9 - 662.9	304.2	253.2	.72 - 7.5	3.5	2.3
Cu	4.4 - 15.9	11.1	14.3	.12 - .18	.142	0.14
Zn	8.1 - 59.4	30.8	25.5	.21 - .58	.364	0.25
Pb	2.8 - 44.2	21.8	24.5	.06 - .50	.256	0.24
Ni	0 - 1.1	0.7	1.0	0 - .01	.007	0.01
Fe	103.5-1149.0	49.30	495.4	2.2 - 13.0	5.76	4.5
Mn	17.9 - 67.2	44.3	54.1	.53 - .63	.572	0.56
As	.16 - 2.5	2.1	2.1	.018 - .023	.02	0.02
Sn	0 - 35.4	9.1	0.6	0 - .4	.092	0.011
Cr	2.0 - 2.0	2.0	2.0	.02 - .02	.02	0.02
Cd	0.0 - 0.0	0.0	0.0	0 - 0	0	0

TABLE 2.22
Metals Load and Concentration Summary
For USGS Gauge

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	12.4 - 269.9	101.1	20.9	.11 - 1.5	.358	.245
Cu	5.9 - 44.3	20.9	12.5	.07 - .41	.182	.15
Zn	3.2 - 29.3	12.5	5.0	.04 - .13	.068	.06
Pb	2.2 - 22.2	9.6	4.4	.02 - .17	.110	.1
Ni	0.0 - 0.0	0.0	0.0	0 - 0	0	0
Fe	32.8 - 468.8	180.1	38.7	.62 - 2.4	1.29	1.055
Mn	10.7 - 582.1	201.3	11.0	.18 - .49	.394	.28
As	0.18 - 35.1	17.6	17.6	.008 - .018	.013	.013
Sn	.06 - 1.0	0.4	0.1	0 - .136	.017	.001
Cr	0 - 0	0	0	0 - 0	0	0
Cd	0 - 0	0	0	0 - 0	0	0

TABLE 2.23
Metals Load and Concentration Summary
For Sweetwater

Constituent	Loads (lbs)			Avg Conc (mg/l)		
	Range	Mean	Median	Range	Mean	Median
Al	35.9 - 482.6	132.8	47.0	.43 - 8.5	2.74	1.8
Cu	1.4 - 23.5	9.5	6.5	.06 - 1.1	0.35	.12
Zn	5.1 - 34.6	14.0	8.1	.15 - .61	0.316	.30
Pb	3.5 - 35.2	15.9	9.0	.015 - .62	.275	.19
Ni	0.5 - 3.4	1.9	1.9	.01 - .06	.035	.035
Fe	74.4 - 851.7	358.5	254.	1.7 - 15	6.55	4.75
Mn	5.6 - 21.0	11.2	7.1	.15 - .37	.253	0.24
As	0 - .14	.07	.07	0 - .003	.0015	.0015
Sn	0 - 1.7	.57	.02	0 - .03	.01	.001
Cr	-	-	-	-	-	-
Cd	0 - 0	0	0	0 - 0	0	0

characteristics. Graphical summaries of first flush observations are presented in Appendix B.

End-of-Pipe Stations: In general, first flush effects were observed for TSS, phosphorus, and phosphate at Hemlock Road, but for only phosphorus and phosphate at Addison-Wesley. Unfortunately, only two storms were usable in the analysis so no generalized conclusions can be drawn. TKN, ammonia and nitrate concentrations revealed no first flush effects and remained relatively unchanged throughout the course of each storm.

USGS Gauge: No first flush effects were observed for any constituent. Concentrations remained relatively constant during storms. The impoundments upstream and the mixture of runoff from the various subbasins with varying times of concentration tend to damp out any concentration variations. The impoundments could be acting as mixing tanks and providing dilution capabilities as constituent concentrations are consistently lower and more uniform at the gauge than at Washington Street.

Mishawum Road: First flush effects were observed for TSS, phosphorus, and phosphate. Concentrations of the nitrogen compounds (TKN, ammonia, and nitrate) remained generally constant within each storm.

Washington Street: Results at this site were similar to those obtained at Mishawum Road with flushing effects observed for TSS, phosphorus, and phosphate. TKN and nitrate remained constant with ammonia concentrations increasing during the course of a storm.

2.6.2 Particulate vs Dissolved Concentrations

Wet-weather quality samples taken as part of this study were analyzed for particulate and dissolved fractions of the nitrogen and phosphorus forms. Table 2.24 presents ratios of dissolved to particulate fractions of total phosphorus, orthophosphate, ammonia, and TKN, at the end-of-pipe and instream sampling stations.

In general, phosphorus and orthophosphate in runoff from the end-of-pipe stations is about 60 to 70 percent dissolved while instream levels are between 40 and 50 percent dissolved. Ammonia is about 80 to 90 percent dissolved at both end-of-pipe and instream stations. TKN, on the other hand, is closer to 80 percent dissolved in the Aberjona River, and about 60 percent dissolved at the end-of-pipes. The proportions of dissolved to particulate observed in this study are well within the ranges observed in other areas of the country.

TABLE 2.24

RATIOS OF FILTERED TO NONFILTERED CONCENTRATIONS
FOR END OF PIPES AND ABERJONA RIVER

Location	Constituent	Ratios of Filtered/Nonfiltered			
		Mean	Std. Dev.	Range	Median
Addison- Wesley	Total P	0.67	0.08	0.54 - 0.81	0.67
	Orthophosphate	0.64	0.06	0.18 - 1.00	0.70
	Ammonia	0.86	0.14	0.48 - 1.00	0.51
	TKN	0.63	0.28	0.15 - 1.00	0.68
Hemlock Road	Total P	0.65	0.21	0.34 - 1.00	0.66
	Orthophosphate	0.84	0.18	0.47 - 1.00	0.92
	Ammonia	0.75	0.22	0.37 - 1.00	0.79
	TKN	0.56	0.21	0.21 - 0.91	0.55
Aberjona River*	Total P	0.43	0.29	0.04 - 1.00	0.35
	Orthophosphate	0.48	0.26	0.02 - 1.00	0.42
	Ammonia	0.88	0.14	0.02 - 1.00	0.91
	TKN	0.78	0.23	0.06 - 1.00	0.82

* Includes data from Mishawum, Mill, Washington and Gauge Sampling Sites.

The instream ratios represent combined results from four sampling stations. Discussions of how the ratios vary as one progresses downstream is deferred until the next chapter, where instream dynamics like plant uptake and deposition are described.

2.7 Comparisons with Other Data

Median constituent concentrations measured in the Upper Mystic Lake watershed were compared with average concentrations observed in stormwater runoff in other parts of the country as displayed in Table 2.25. Variations in stormwater quality can be expected from region to region, and for different land uses. However, in general, there is much consistency in measured concentrations for many constituents in the literature.

Nutrient, BOD, and bacteria observations from the Mystic wet-weather sampling program fall well within the range of constituent concentrations measured in other parts of the country. For example, phosphorus concentrations are typically in the range of 0.1 to 1.0 mg/l and usually average about 0.2 mg/l. In this study, except for Sweetwater Brook, median phosphorus concentrations ranged from 0.1 to 0.2 mg/l for all sampling stations. Stormwater samples taken on Sweetwater Brook averaged about 0.4 mg/l, still within values observed elsewhere. TKN and ammonia concentrations at Mishawum Road, however, are above typical literature values. Nitrogen leachate from the Olin Chemical site upstream of the Mishawum Road sampling site is believed to be the source of the uncharacteristically high concentrations.

The concentrations of heavy metals in the limited number of Mystic wet-weather samples are also very representative of those found elsewhere. It is difficult to make such comparisons, as the literature values vary over several orders of magnitude due to the local land use and other site-specific conditions, but the Mystic values seem very reasonable.

Except as noted, concentrations measured in the Upper Mystic Lake watershed are in close agreement with literature values for the same constituents. Such concordance shows the Upper Mystic watershed to be typical of other basins in the country and fosters confidence in selecting literature values for parameter values for which no field data are available. The latter is especially true in determining washoff rates for the STORM analysis, as described in Chapter 3.

TABLE 2.25

UML Watershed Concentrations vs Literature ValuesLiterature Values¹ (mg/l)

Land Use	TSS		VSS		Phosphorus		TKN		Nitrate		Ammonia	
	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
Light Industry	300	8-3000	35	3-360	0.2	.01-1.5	1.4	0.5-3.6	1.2	0.1-4	0.4	0.1-1.3
Commercial	400	25-2900	45	5-160	0.2	.02-2.2	2.0	0.8-4.5	1.6	0.3-3	0.5	0.1-1.3
Single Family	500	25-6000	55	2-500	0.14	.01-0.7	1.7	0.4-8	1.4	0.1-7	0.5	0.1-2.3
Multi-Family	800	25-3500	70	9-300	0.23	.04-0.7	2.1	1.3-7.4	1.1	0.2-3	0.5	0.1-2.2

UML Watershed Median Concentrations (mg/l)

Instream	TSS	VSS	Phosphorus	TKN	Nitrate	Ammonia
Mishawum	30	11	0.2	14.5	2.0	4.5
USGS Gauge	13	6	0.1	3.8	3.0	2.4
Sweetwater	180	76	0.4	4.1	2.0	0.4
End-of-Pipes						
Hemlock	62.5	41	0.3	13.0	2.9	0.3
Addison-Wesley	45	9	0.1	2.0	1.1	0.4

- ¹Sources: 1. Polls, I. and Lanyon, Richard, "Pollutant Concentrations From Homogeneous Land Uses," Journal of the Environmental Engineering Division, ASCE, Vol. 106, February 1980.
2. Browne, F.X., "Nonpoint Sources," Journal of the Water Pollution Control Federation, Vol. 51, June 1979.
3. Mattraw, H.C., Jr., and Sherwood, C.B., "Quality of Stormwater Run-off From a Residential Area, Broward County, Florida," USGS Journal of Research, Vol. 5, 1977.

CHAPTER 3

CHARACTERIZATION OF URBAN RUNOFF

QUANTITY AND QUALITY FOR

THE UPPER MYSTIC LAKE WATERSHED

3.1 Model Application and Philosophy

This chapter describes the theory and use of the Storage Treatment Overflow Runoff Model (STORM), which was applied to the Upper Mystic Lake watershed to compute the long-term quantity and quality characteristics of urban runoff. First, a general description of the model and its underlying philosophy is provided; then its application to the Mystic Lake watershed is described.

STORM is a continuous simulation model capable of computing point and nonpoint loadings of numerous water quality constituents over long simulation periods. Simulation results include the quantity and quality of runoff from urban and nonurban watersheds. STORM provides output on the quantity and quality of pollutants washed off the land surface, which can be summarized on an hourly, daily, monthly, or yearly basis. The Receiving Water Quality Model (RWQM) is a module of STORM that simulates receiving water impacts of the discharges computed by STORM. Its application to the Aberjona River is discussed in Chapter 4.

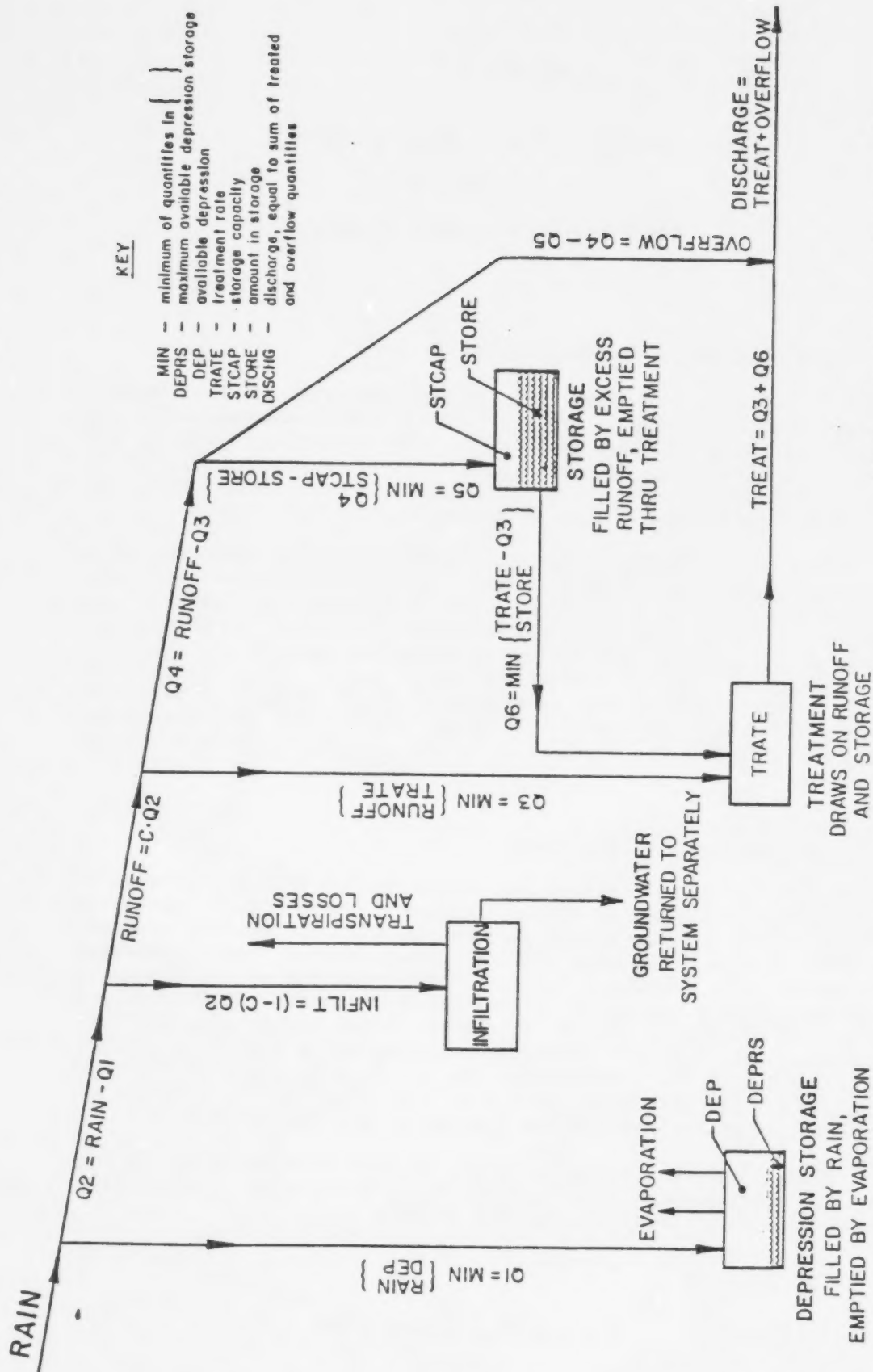
3.1.1 Stormwater Flow Simulation

Figure 3.1 shows a schematic representation of the stormwater flow elements modeled by STORM. Initially rainfall fills depression storage, which includes ground surface saturation, surface puddles, pavement cracks, and other similar surface storage. Once depression storage is full, additional rainfall infiltrates the ground surface up to some limited capacity. Excess rainfall washes dust and dirt and associated pollutants off the watershed. The model also has the capability to simulate baseflow augmentation by the water that has infiltrated into the groundwater. The runoff water can also be routed through storage-treatment facilities to simulate the effects of implementing control devices for quality or quantity effects.

STORM simulates a basin water balance independently of the quality simulation. Direct runoff from precipitation is computed in hourly time steps using the Rational Formula (3.1):

$$Q = CIA \quad (3.1)$$

where: Q = runoff flow rate (cfs)



NOTE: EXCLUDING SANITARY FLOW

FIGURE 3.1
STORM Schematic

C = runoff coefficient, which is
related to land use
I = rainfall intensity (inches/hour)
A = drainage area (acres)

An hourly rainfall record is linked to STORM and initiates the simulation process.

Although the Rational Formula was originally designed to predict peak flows, it is used in STORM to compute total hourly overland runoff flow that results from the rainfall over that hour. Before runoff can begin, available depression storage must fill. Depression storage represents areas such as parking lots, where ponding and precipitation-interception occurs, and the value varies with land use. Water entering depression storage is removed by evaporation during subsequent dry periods. Numerically, this translates to:

$$I_r = I - D \quad (3.2)$$

where: I = rainfall intensity
D = available depression storage
 I_r = modified rainfall intensity

Depression storage varies by land use. In open space areas the capacity for trapping and ponding runoff in topographic depressions is much greater than in commercial/industrial areas where blacktopped parking lots generally slope to a common catchment. Typical depression storage values range from 0.4 to 0.8 inch for open space; 0.1 to 0.2 inch for residential areas; and 0.05 to 0.1 inch for commercial/industrial areas (Dorchester Bay CSO Study - CDM, 1980).

Combining equations (3.1) and (3.2) results in the formulation used by the model for runoff:

$$Q = C * (I - D) * A \quad (3.3)$$

3.1.2 Stormwater Quality Simulation

The results of the runoff flow component of STORM serve as input to the quality computation. The removal of pollutants from the ground surface is related to the amount of water washing off the surface and the pollutants available on the surface.

The pollutant loading component of STORM assumes that pollutants on the land surface available for washoff by overland flow are related to land use. It is generally accepted in the literature that pollutants accumulate on the land surface at a diminishing rate as the dry period following a runoff-producing rainfall lengthens (APWA, 1979).

The pollutant accumulation algorithm is:

$$AC = P_{\max} \frac{HAFSAT}{(HAFSAT + t)^2} \quad (3.4)$$

where: AC = pollutant accumulation (lb/acre/day)
 $P_{\max}$ = maximum accumulation of pollutant by land use (lb/acre)
 HAFSAT = half saturation constant or time at which accumulation is half the maximum value (days), and
 t = time since runoff ended (days)

Note that the smaller the value of HAFSAT used, the faster pollutant accumulation occurs. Figure 3.2 presents a graphical interpretation of accumulation rates as computed by equation (3.4) for different HAFSAT rate values.

Once the pollutant accumulation on each land use has been computed for an interstorm period, the rate of washoff to the local receiving waters is calculated using a first order rate equation (3.5).

$$\frac{d P_L}{d t} = K P_L \quad (3.5)$$

where: K = washoff rate related to runoff intensity and dry hours

P_L = total pollutant load for land use L

The washoff rate k is assumed to be directly proportional to the runoff rate. For example, assuming that a runoff rate of 0.5 inches per hour will remove 90 percent of the TSS load in one hour, the washoff rate has a value of 4.6, where R is the instantaneous runoff rate in inches per hour. This value is obtained in the following manner. Substituting this value for k, integrating equation (3.5), and rewriting:

$$P_{L_{t+\Delta t}} = P_{L_t} \exp(-4.6 R \Delta t) \quad (3.6)$$

where: P_{L_t} = TSS load at time t

$P_{L_{t+\Delta t}}$ = TSS load remaining at time t + Δt

t = one hour

If 90 percent of the TSS load is removed, then 10 percent remains, or:

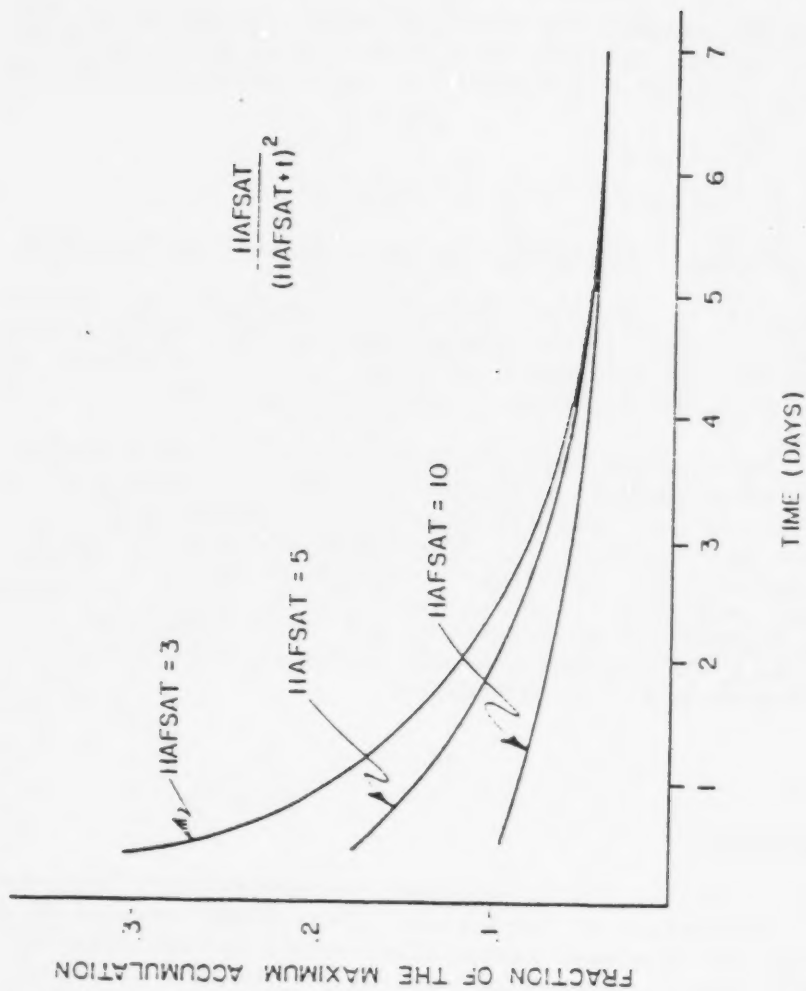


FIGURE 3.2
 Fraction of Maximum Accumulation as a Function of
 Time for Different Half Saturation Constants
 as Simulated by STORM

$$0.1 = \exp(-k R \Delta t) = \exp(-0.5 k) \quad (3.7)$$

Since t equals one hour and R equals 0.5, then k must equal 2.3, or 4.6 R . The value of k is thus related to best represent the conditions in a specific watershed.

Substituting this value for k into equation (3.6) and rearranging terms gives:

$$P_{L_t + \Delta t} = P_{L_t} \exp(-4.6 R \Delta t) \quad (3.8)$$

Therefore, STORM computes the total pollutant accumulation for each dry period using equation (3.4), and washoff during a runoff producing storm is computed as a function of the rainfall intensity by equation (3.8).

3.2 STORM Model Parameter Values for the Upper Mystic Lake Watershed

STORM was applied to the Upper Mystic Lake watershed to compute the quantity and quality of runoff throughout the area. These values are used as input for the computation of water quality reactions in the Aberjona River and pollutant loads to Upper Mystic Lake.

Runoff coefficients were computed based on rainfall gauge records and streamflow measurements. Pollutant buildup rates were based on field data collected at the Hemlock Road, Mishawum Road, and Sweetwater Brook sampling stations. The "data" collected during this study were not suitable for computing a consistent set of washoff rates or HAFSAT constants. As a result, the values of these parameters were estimated from experience and the literature. The data inconsistencies and the origin of the literature values that were used are described in detail in Section 3.6.

3.3 Basin Segmentation

When STORM is applied, it is necessary to divide the watershed into a number of segments or sub-basins. Since STORM operates on an hourly time step, the watershed segmentation should follow hydrologic boundaries, and should result in a set of sub-basins with times of concentration approximating one hour. Land uses are determined for each sub-basin, as many sub-basin parameter values, such as runoff coefficients, depression storage values, buildup rates, half-saturation constants, and washoff rates are a function of land use type.

Segmentation of the Upper Mystic Lake watershed was based primarily on hydrologic boundaries, location of instream sampling stations, and location of major inflows. In total seven sub-basins were used in the discretization of the watershed as shown in Figure 3.3. Drainage boundaries for each sub-basin are also presented in Figure 3.3. Three additional sub-basins, which drain directly to the lake, are also delineated but were not included in the calibration.

Barn Tributary (1800 acres), Sweetwater Brook (1450 acres), and Horn Pond Brook (1145 acres) are the major tributaries of the Aberjona River and STORM sub-basins were established for each of these sub-watersheds. Delineation of the Mishawum Road sub-basin (4021 acres) is also based on hydrologic boundaries.

The remaining sub-basins, Direct Aberjona Drainage (1650 acres), Muraco School (620 acres), and Highland Avenue (620 acres), are not tributaries of the Aberjona but sub-basin delineation was based on hydrologic boundaries as developed from USGS quad sheets and town drainage plans.

In total, three sub-basins (Mishawum Road Basin, Barn Tributary Basin, and Sweetwater Brook Basin) drain to EDP field sampling locations and runoff coefficients determined from field data were available for each.

Runoff coefficients for the remaining four basins, where no field data were collected, were estimated for each land use using values developed during the initial calibration effort. The four sub-basins include: Horn Pond, Highland Ave., Muraco, and the remaining direct drainage to the Aberjona River.

All 6,518 acres of the Horn Pond Basin were not included in the calibration. Wells adjacent to Horn Pond are used for water supply by the Town of Woburn, causing low pond levels throughout most of the year. In an effort to maintain pond levels, flashboards have been placed at the outlet of the pond. Conversations with town officials disclosed that, except for two months a year, no discharge from Horn Pond occurs. Consequently, since no flow through Horn Pond occurred during the field sampling program, all drainage upstream of the outlet was disregarded, effectively reducing the sub-basin area from 6,518 acres to 1,145 acres.

3.4 Baseflow

Average annual streamflow at the USGS gauge is approximately 27 cfs, based on data collected between 1920 and 1981. Existing data collected during dry weather periods indicate that about half of this value is baseflow from groundwater sources. The results of the STORM model application were input to the receiving water flow along with baseflow for water quality computations using RWQM.

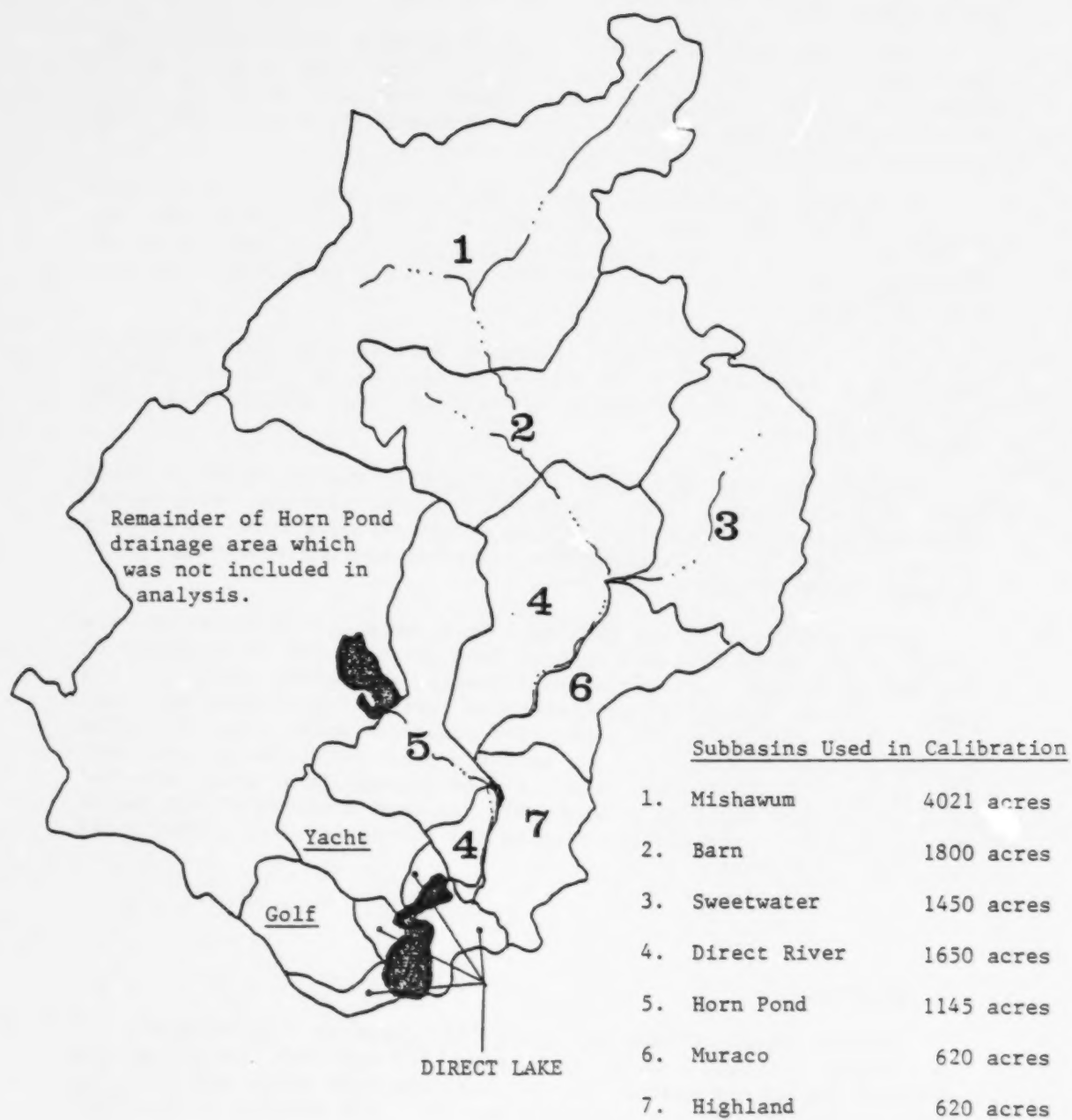


Figure 3.3

Segmentation of Upper Mystic Lake Watershed into STORM Subbasins

Average annual precipitation in the Upper Mystic Lake basin is approximately 42 inches/year, and long-term basinwide gauge records show average annual streamflow equal to 27 cfs or 23 percent of the total average annual rainfall. However, less than half of the total flow is baseflow, and 0.13 is an appropriate runoff coefficient for the urban runoff fraction of the total flow. This value represents a long-term annual average; actual runoff will vary from storm to storm, and is a function of antecedent soil conditions, storm pattern, snow cover, etc. Nevertheless, because long-term impacts and storm loadings are being assessed, use of an annual average runoff coefficient is appropriate for calibration of annual totals.

The runoff coefficients derived above are for the entire watershed. They must be corrected for use in STORM, as depression storage is considered, and the runoff coefficient is obtained by dividing runoff volume by the rainfall volume less depression storage volume. Consequently, to arrive at a net runoff coefficient of 0.13 for the watershed, a STORM model coefficient of 0.21 was used which was effectively reduced by depression storage to yield the 0.13. Flow data collected at the gauge as part of this study verified the appropriateness of this value. Runoff coefficients averaged 0.11 at the gauge for the seven storms sampled. Since the sampling program did not always cover an entire storm, the field measured coefficients are not entirely accurate. Thus, calibration efforts were aimed at obtaining a long-term average runoff coefficient of 0.13 at the gauge.

3.5 Calibration of STORM For Hydrology

Calibration efforts were initiated by considering the entire watershed as a single sub-basin. The hydrology or water balance only was simulated in this manner, and the results were used to develop basinwide hydrologic parameter values. The initial simulation covered the watershed upstream of the USGS gauge, which provides a convenient location for checking simulated values against observed.

Originally the Mystic watershed was divided into the five land use categories used in the Mystic Hydrology Study: low-density residential; medium-density residential; office park/industrial; commercial; and other. In an effort to obtain more meaningful land use breakdowns, that better correspond with field survey observations, and eliminate the ambiguity associated with the "other" land use, existing land uses were aggregated into three groups: low- and medium-density residential land use were combined into residential, office park/industrial and commercial land use were combined into commercial/industrial and finally, other land use was reclassified as open space. Figure 3.4 presents the land uses graphically, and Table 3.1 is a land use breakdown for each sub-basin. Both a runoff coefficient and a depression storage value must be specified for each land use.

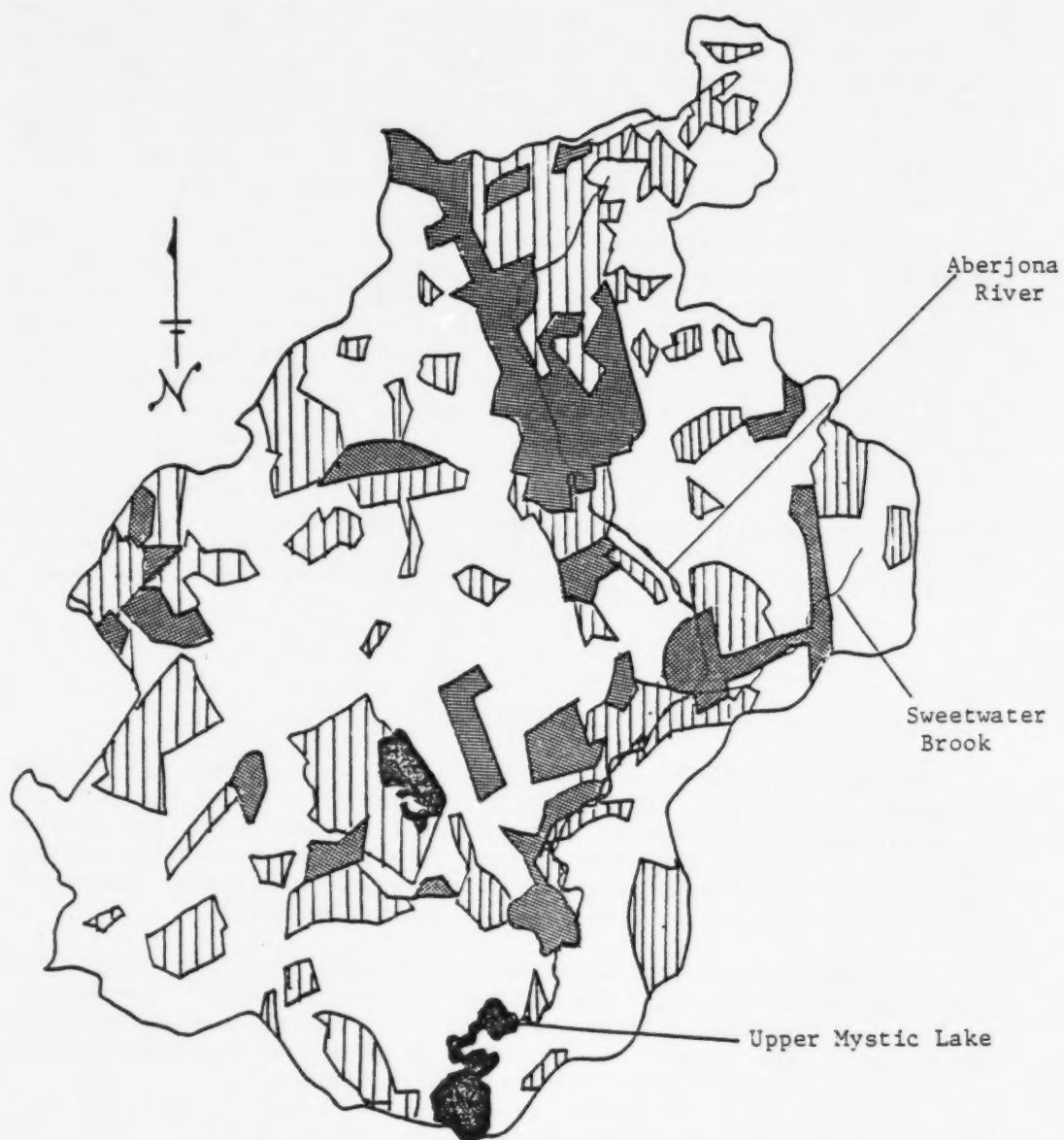


Figure 3.4
Land Use in Upper Mystic Basin

LEGEND

- Commercial/Industrial
- Open Space
- Residential

Scale: 1" = 1 mile

TABLE 3.1

LAND USE OF STORM SUBBASINS

Subbasin	Drainage Area (acres)	L A N D U S E		
		Open Space	Residential	Commercial/ Industrial
Mishawum	4,021	38%	43%	19%
Sweetwater	1,450	15%	80%	5%
Barn	1,800	19%	69%	12%
Muraco	620	30%	60%	10%
Horn Pond	1,145	28%	65%	7%
Highland	620	30%	60%	10%
Direct River	1,650	40%	51%	9%

For the Upper Mystic Lake basin, runoff coefficients for open space, residential, and commercial/industrial land uses were 0.12, 0.23, and 0.46, respectively, and were based on values determined in the Mystic River Hydrology Study (CDM, 1981). Corresponding depression storage values were 0.4, 0.12, and 0.05 inches, respectively, and were based on values determined in the CSO Study of Dorchester Bay (CDM, 1980). The initial calibration of STORM was carried out using seven years (1970-1976) of rainfall data from Logan Airport. Subsequent calibrations using the individual sub-basins used the three year period 1973-1975. These simulation periods are representative of the average annual rainfall in the area, and contain a wide variety of storm and runoff conditions. Therefore, they provide a representative period over which to apply the simulation models.

Evaporation rates (inches/day) for the months of April through August were based on monthly pan data recorded at the Chestnut Hill Reservoir. For the remaining months, evaporation rates were based on representative data for the New England area reported in the Climatic Atlas of the United States (U.S. Department of Commerce, 1974).

Calibration results yielded an effective average runoff coefficient of 0.13, and total runoff volume was within 96% of measured runoff during that time period.

After the hydrology calibration was completed for the watershed as a whole, the exercise was repeated at a more detailed level, using the seven sub-basins. Flow data collected as part of the field program were incorporated into the analysis. Runoff coefficients from the Sweetwater, Mishawum Road, and Mill Street sampling stations were used for the Sweetwater, Mishawum and Barn sub-basins. Table 3.2 presents the runoff coefficients used in the STORM analysis.

The results of this calibration compare favorably with initial calibration results. Summing results for each sub-basin, an average runoff coefficient of 0.14 for the three-year simulation period was obtained. Total volume of runoff was within 96% of that measured at the gauge during the simulation period. Thus, a successful calibration of the hydrology component of STORM was achieved.

3.6 Calibration of STORM Pollutant Loadings

Pollutant loadings associated with overland flow in STORM are assumed to be directly related to land use. Pollutants accumulate on the land surface at a diminishing rate during dry periods following a runoff event as expressed by equation (3.4) and Figure 3.2. Equation (3.4) is a two parameter function; values for the maximum pollutant buildup and the HAFSAT are needed.

An effort was made to estimate buildup rates and HAFSAT values from field data. For each of the storms sampled, total pollutant load was compared with antecedent dry period for the Addison-Wesley and

TABLE 3.2

RUNOFF COEFFICIENTS AND DEPRESSION STORAGE VOLUMES
USED IN STORM SIMULATIONS

<u>Subbasin</u>	Average Field Measured Runoff Coefficient*	STORM Values	
		<u>Depression Storage (inches)</u>	<u>Runoff Coefficient***</u>
Mishawum	0.17	0.27	0.20
Sweetwater	0.21	0.16	0.21
Barn	0.14**	0.17	0.13
Muraco	NM	0.20	0.16
Horn Pond	NM	0.19	0.15
Highland	NM	0.20	0.15
Direct	NM	0.23	0.14
Gauge	0.11	0.20	0.14

NM = Not Measured

*Based on data collected for 7 Storms by EDP.

**Based on data collected at the Mill Street sampling site.

***Obtained from STORM output summaries by dividing total runoff volume by total rainfall volume.

Hemlock sampling stations. Two antecedent dry periods were examined:

- 1) the number of days since last measurable rainfall, and
- 2) the number of days since last "flushing" rainfall

A "flushing" rainfall was defined by CDM as a storm with a total precipitation exceeding 0.1 inch. Some storms are marked by minimal precipitation over long periods (drizzle), and pollutant washoff is negligible. In the Mystic watershed, storms with precipitation exceeding 0.1 inch generally contain at least one hour of sufficient rainfall intensity to wash accumulated pollutants off the land surface.

Total load for each storm was divided by drainage area and antecedent dry period to arrive at a buildup rate in pounds/acre/day. These rates are presented in Table 3.3. Consistent buildup rates were observed for phosphate and ammonia at Hemlock, (except for the August 5 storm). Buildup rates for TSS, phosphorus, and nitrate varied considerably from storm to storm. At the Addison-Wesley sampling station, the only constituent which produced consistent results was phosphate.

These results are not unusual for urban runoff data. The quality characteristics of stormwater vary significantly from storm to storm, and the data for the Mystic watershed are similar. Since the simulation models applied compute long-term average loading values, it was important to select parameter values that represent such characteristics of the runoff quality. Therefore, the field data were analyzed, and representative values for buildup rates that describe the long-term average characteristics were selected for each land use.

An attempt was made to use field data to develop HAFSAT values. Total load for each sampled storm at four sampling sites was plotted against antecedent dry period. A smooth exponential curve leveling off at some maximum value would fit the model equation precisely. Unfortunately, the plotted points for the field data showed much scatter. Figures 3.5 and 3.6 show the results of plotting phosphate loads for each storm against antecedent dry period for the Hemlock and Addison-Wesley sites. The August 5th storm, in particular, gave poor results: plotted points (6 day antecedent dry period) were consistently lower for phosphate and every other constituent at each location than other storms with smaller antecedent dry periods. Thus, reliable HAFSAT values could not be determined with the available field data which necessitated using previously published literature values. The inconsistent results could be due to difficulty in estimating the true antecedent dry period, problems with composite sampling intervals, or the inherent variability of urban runoff quality. Based on CDM's experience with STORM, a value of 2.0 was selected. This selection assumes that the buildup reaches half of its maximum value after two days.

TABLE 3.3

POLLUTANT BUILDUP RATES AT END OF PIPE STATIONS

Date of Storm	Antecedent Dry Period-Time Since:		Pollutant Buildup ¹ (lb/acre/day)									
	Last Rain	Flushing Rain ²	TSS		TP		PO ₄		NH ₃		NO ₃	
			Last	Flush	Last	Flush	Last	Flush	Last	Flush	Last	Flush
<u>ADDISON-WESLEY</u>												
04/02/81	6	7	1.12	0.96	.0004	.0003	.0009	.0007	.0002	.0002	.013	.011
04/14/81	3	8	0.12	0.04	.0004	.0002	.0003	.0001	.0040	.0002	.007	.003
06/22/81	2	2	3.3	3.3	.0042	.0042	.0009	.0009	.0120	.0120	.058	.058
07/13/81	3	8	1.12	0.44	.0050	.0018	.0015	.0006	.0210	.0080	.046	.017
08/05/81	6	6	0.09	0.09	.0009	.0009	.0003	.0003	.0020	.0020	.009	.009
<u>HEMLOCK ROAD</u>												
04/14/81	3	8	0.18	0.07	.0015	.0006	.0012	.0005	--	--	--	--
06/20/81	8	11	1.16	0.84	.0043	.0031	.0021	.0015	.003	.002	.008	.006
06/22/81	2	2	0.09	0.09	.0020	.0020	.0009	.0009	.004	.004	.033	.033
07/13/81	3	8	0.63	0.24	.0030	.0011	.0022	.0008	.002	.002	.034	.012
08/05/81	6	6	3.81	3.81	.0270	.0270	.0122	.0122	.040	.040	.187	.187

$$^1\text{Buildup} = (L/A)/t$$

where: L = Pollutant Load for Storm (lb)
 A = Drainage area (acres)
 t = Antecedent dry period (days)

²Flushing rain > 0.1 in.

LOAD VS. ANTECEDENT DRY PERIOD

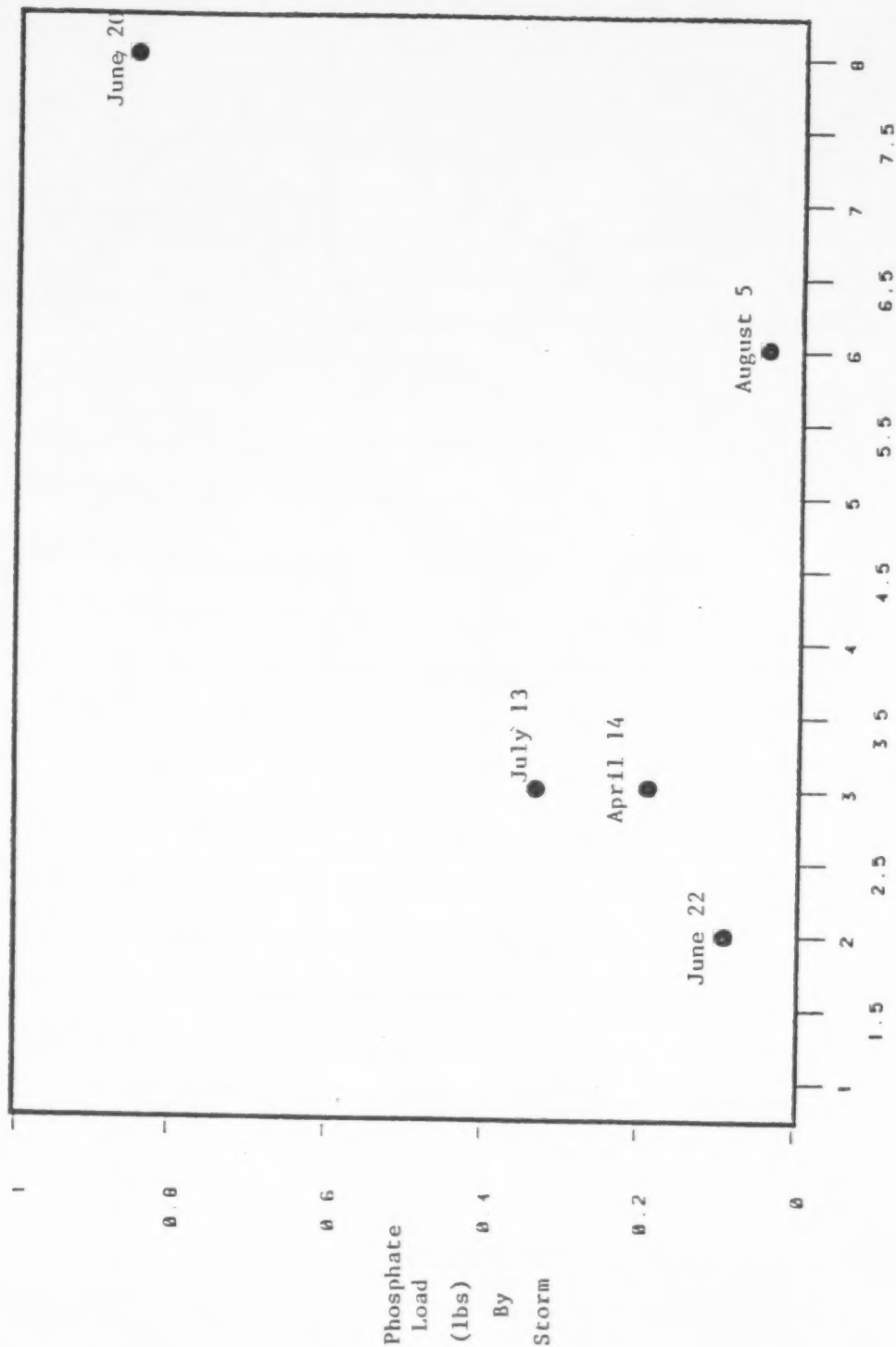


Figure 3.5

Phosphate Loads vs Antecedent Dry Period at Hemlock Road

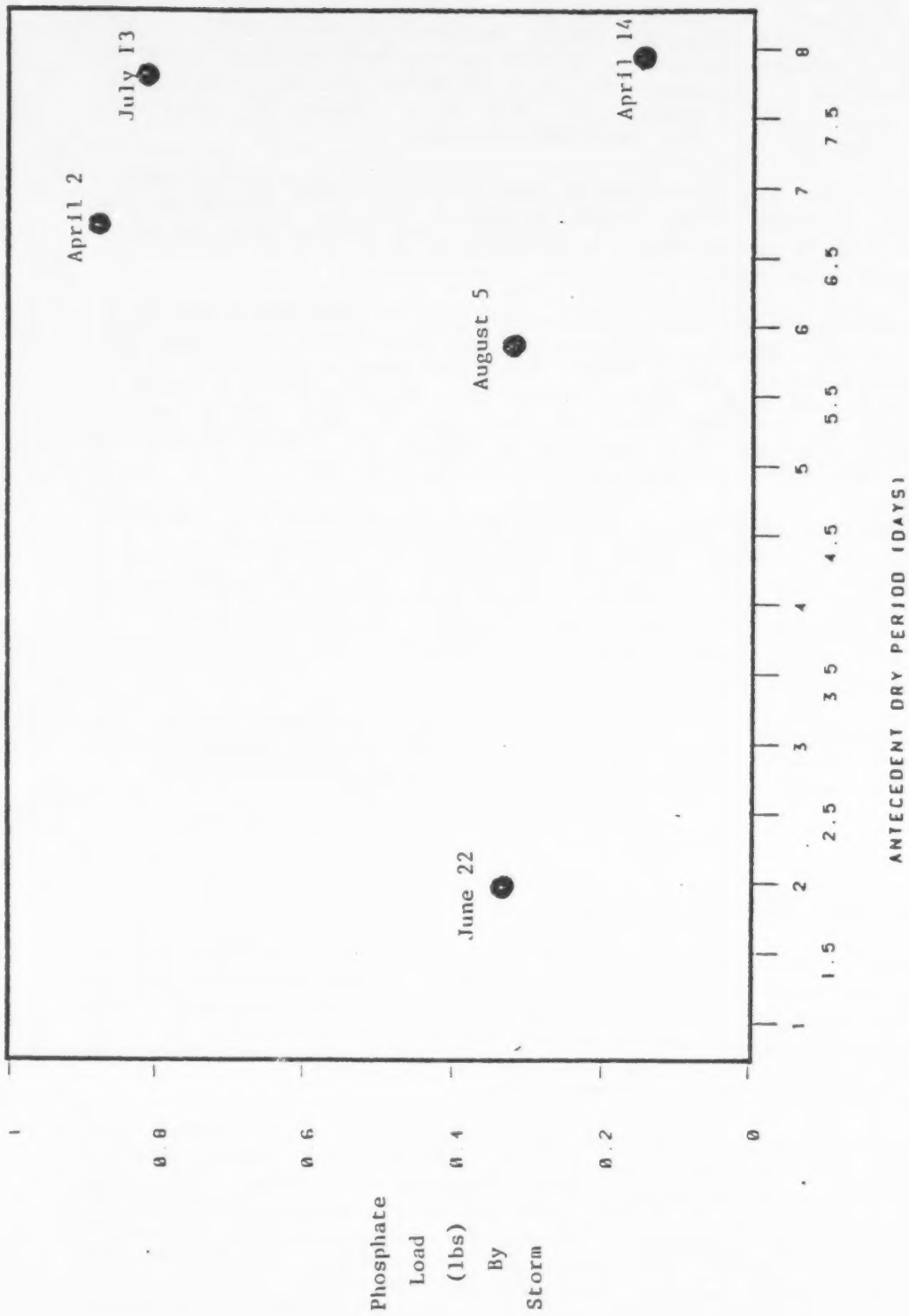


Figure 3.6

Phosphate Loads vs Antecedent Dry Period At Addison-Mesley

3.6.1 Calibration of Buildup and Washoff Rates for STORM sub-basins

Buildup rates were computed for the calibration of the water quality component of STORM for total suspended solids (TSS), total phosphorus (TP), orthophosphate (PO_4), nitrate-nitrogen (NO_3), BOD, and total Kjeldahl-nitrogen. Initial values were adjusted to match program field data. Successful model calibration was achieved using the buildup rates listed in Table 3.4. Table 3.5 presents representative buildup rates observed elsewhere.

A three-year simulation period (1973-1975) was used in the model calibration. These three years represent "typical" rainfall years (approximating 42 inches/year), a necessary condition when calibrating long-term average loadings.

Reliable washoff rates could not be computed from the field data because of the great variations in loads from storm to storm. The Users Manuals for the models STORM and SWMM suggest washoff rates between 1.0 and 4.6. After reviewing individual storm loads, a washoff rate of 2.0 was selected for use in the Mystic basin. Sensitivity analyses were conducted to assess the effects of varying washoff, and results are presented in the next section.

Calibration of STORM was based on median concentrations measured for the seven sampled storms, as they are more representative of the actual observed loadings than mean loadings. The large June storm tended to raise mean concentrations to an uncharacteristically high value. The use of these values would lead to an over-estimation of pollutant loads, and would misrepresent the urban runoff characteristics in the area.

The results were ultimately used as input to RWQM, which was calibrated against the observed instream concentrations. This provided a second check on the validity of the model results.

3.6.2 Initial Calibration Results

Table 3.6 displays the results of the calibration efforts for the Hemlock, Mishawum, and Sweetwater sub-basins. STORM-generated average pollutant concentrations and loadings are in close agreement with field-measured median concentrations and computed loadings. In every case, STORM-generated average pollutant concentrations are within 15% of field-measured median concentrations.

Since washoff rates and half saturation values were held constant, the buildup rates were the only parameters manipulated in the calibration of the water quality component of STORM. By using this procedure the field data were used to the extent possible. The washoff and half saturation values are representative of values determined elsewhere, and manipulation of their values for this application would be for the purposes of curve fitting only. Sensitivity analyses were conducted to assess the effects of varying

TABLE 3.4

BUILDUP RATES USED IN STORM CALIBRATION

Subbasin	L A N D U S E			B U I L D U P R A T E S (LB/ACRE/NO.)					
	Open Space	Residential	Commercial/ Industrial	TSS	PO ₄	NO ₃	TKN	TP	BOD
Hemlock	15%	85%	0%	12.5	0.04	0.6	0.5	0.06	1.9
Mishawum	38%	43%	19%	5	0.007	0.4	1.05	0.01	0.75
Sweetwater	15%	80%	5%	30	0.07	0.3	0.7	0.10	4.5

TABLE 3.5

REPRESENTATIVE MEASURED POLLUTANT BUILDUP RATES
(pounds/acre/year)

<u>Constituent</u>	<u>Land Use</u>	<u>Buildup Rate Range</u>
Phosphorus	Urban/Residential	0.2 - 4.5
Phosphorus	Commercial	0.02 - 2.56
Phosphorus	Industrial	0.3 - 6.9
Phosphorus	Developing	0.6 - 1.0
Phosphorus	Natural	0.01 - 0.68
TSS*	Urban/Residential	150 - 2000
TSS	Commercial	50 - 1000
TSS	Industrial	350 - 1500
TSS	Developing	25 - 500
BOD	Urban/Residential	10 - 73
BOD	Commercial	22 - 78
BOD	Industrial	16 - 100
BOD	Agricultural/Natural	4.5 - 20

* Total Suspended Solids

Source: Camp Dresser & McKee, Inc. "Final Report On Assistance
In Mathematical Modeling of Water Quality," June 1982.

TABLE 3.6

RESULTS OF STORM CALIBRATION

Subbasin	Constituents	Field Measured Values		STORM-Generated Values	
		Median ¹ Concentration (mg/l)	Load ² (lbs)	Avg. Concentration ³ (mg/l)	Load ⁴ (lbs)
Hemlock Road	TSS	62.5	30,080	55.0	27,485
	PO ₄	0.2	96	0.2	88
	NO ₃	2.9	1,395	2.7	1,320
	TKN	2.3	1,110	2.2	1,100
	TP	0.3	144	0.3	132
	BOD	4.3	2,070	4.3	2,150
Mishawum Road	TSS	30.0	808,795	25.0	619,630
	PO ₄	0.04	1,080	0.04	867
	NO ₃	1.8	48,525	2.0	49,570
	TKN	6.4	172,540	5.3	130,120
	TP	0.09	2,430	0.09	1,950
	BOD	7.4	199,500	7.1	176,000
Sweetwater Brook	TSS	188.0	1,593,000	157.0	1,392,000
	PO ₄	0.4	3,390	0.37	3,249
	NO ₃	1.8	15,250	1.6	13,925
	TKN	4.1	34,740	3.7	33,120
	TP	0.6	5,085	0.6	4,870
	BOD	5.5	46,600	5.0	44,330

¹From Seven Storms sampled²Estimated for 3-year period (1973-1975) using equation (3.1)³Total STORM-generated load (1973-1975) divided by total runoff⁴Total for simulation period (1973-1975)

washoff rates and HAFSAT constants. Table 3.7 is a summary of the results for one calibrated sub-basin, Mishawum Road. In general, the amount of pollutant washed off is more sensitive to the washoff rate than the HAFSAT constant. Reducing the washoff rate by fifty percent results in a thirty percent reduction in the amount of phosphorus washed off. On the other hand, increasing the HAFSAT constant by fifty percent causes an increase of phosphorus washoff of only one percent. By testing the range of reasonable washoff rates (1.0 to 4.6) and HAFSAT constants (1.0 to 4.0), one can define a range of reasonable values within which the amount of a given constituent washed off the land surface will fall. STORM was calibrated by varying buildup rates as the results are most sensitive to those values, and they are the parameters that vary most in the field. The choice of 2.0 for the value of HAFSAT and the washoff coefficient is reasonable, and results in the generation of representative pollutant loads.

3.6.3 Calibration of the Remaining sub-basins

With successful calibration of the three sub-basins using available field sampling data, the next step was to assign buildup rates for the remaining sub-basins based on the field data and earlier calibration runs.

Initial selection of buildup rates for the remaining sub-basins was based on comparisons between existing land uses in the sub-basins and those for the earlier calibrated sub-basins. Some judgement was necessary in assigning buildup rates, however. Nitrogen loads in the calibrated Mishawum Road basin were not representative of the entire watershed, because of ammonia leachate originating at the Olin Chemical site. In addition, TSS and phosphorus loads in the calibrated Sweetwater sub-basin are higher than normal because of sanitary sewer cross-connections in that area. Thus, buildup rates were assigned to the sub-basins based on observed values for similar areas and land uses in cases where verification with field data could not be made. Buildup rates and land uses associated with each sub-basin are presented in Table 3.8.

The Barn Tributary sub-basin is similar in land use to the calibrated Sweetwater sub-basin, but the Sweetwater buildup rates are uncharacteristically high in TSS and phosphorus because of the influence of CSOs. Land uses in the Barn Trib sub-basin more closely approximate those in the Mishawum sub-basin than those at Hemlock. The Barn Trib sub-basin is 12 percent commercial/industrial development; Mishawum is 19 percent commercial industrial while Hemlock contains no commercial/industrial development. Thus, buildup rates for Barn Trib sub-basin were based on those calibrated for Mishawum Road. Buildup rates for the Direct River sub-basin were averaged between calibrated values for the Hemlock and Mishawum sub-basins, again based on land use.

Table 3.7

Results of STORM Sensitivity AnalysisMishawum Subbasin

WASHOFF RATE (1/hour)	HAFSAT CONSTANT	Pollutant Washoff* (lbs)			
		TSS	NO ₃	TKN	TP
2.0**	2.0**	619,630	49,570	130,120	1,950
4.6	2.0	1,150,300	90,025	241,560	3,545
1.0	2.0	440,470	35,235	92,500	1,360
2.0	1.0	788,540	63,085	165,590	2,430
2.0	4.0	635,080	50,805	133,370	1.960

* Total for simulation period (1973-1975)

** Values used in calibration

TABLE 3.8

BUILDUP RATES AND LAND USES FOR

SUBBASINS WITH NO FIELD-MEASURED DATA

Subbasin	L A N D U S E			B U I L D U P R A T E S (lb/acre/mo)					
	Open Space	Residential	Commercial/Industrial	TSS	PO ₄	NO ₃	TKN	TP	BOD
Barn	19%	69%	12%	6.0	0.01	0.4	1.0	0.06	4.5
Muraco	30%	60%	10%	9.0	0.01	0.3	0.5	0.02	1.4
Horn Pond	28%	65%	7%	9.0	0.02	0.6	0.5	0.03	1.4
Highland	30%	60%	10%	9.0	0.02	0.6	0.5	0.03	1.4
Direct Drainage (Aberjona)	40%	51%	9%	5.0	0.01	0.3	0.5	0.02	0.8

3.7 Results of STORM Calibration

A summary of average annual simulated pollutant washoff loads for each sub-basin in the Upper Mystic Lake watershed is presented in Table 3.9. These values do not represent average annual loadings to the Lake; they do represent what is washed off the land surface on an annual basis. Removal mechanisms, such as sedimentation, along the Aberjona River reduces the lake loading. A discussion of sinks identified in the STORM analysis is presented in Chapter 4.

As can be seen from Table 3.9, even though Sweetwater Brook comprises only 1,450 acres (11%) of the entire watershed, it contributes a significant amount of TSS and phosphorus to the receiving waters. The Mishawum sub-basin, the largest sub-basin in the watershed contributes relatively small amounts of phosphorus (15%), but significantly large amounts of nitrate and TKN (because of Olin Chemical Company).

3.7.1 Seasonal Washoff

STORM also generates pollutant washoff values on a seasonal basis. Tables 3.10 through 3.15 present seasonal washoff values for each sub-basin for TSS, nitrate, TKN, orthophosphate, total phosphorus, and BOD, respectively. Seasons having more runoff will have correspondingly greater washoff totals. For the simulation period, more precipitation/runoff occurred during the fall and winter seasons.

Tables 3.10 through 3.15 include only the drainage area downstream of the Horn Pond outlet. Should pond operation policy change so that flow out of the pond occurs continuously, then the added amounts of pollutants washed off the land surface would have to be considered. Table 3.16 presents seasonal pollutant washoff for the sub-basin with the remaining 5,373 acres that drain to Horn Pond included in the analysis. When considered in its entirety, the Horn Pond sub-basin would contribute the largest amounts of TSS, phosphorus, and nitrate with only the Mishawum sub-basin contributing greater amounts of TKN. The Horn Pond sub-basin's significant contribution of pollutants is directly related to its size: its drainage areas comprises more than one third of the entire Upper Mystic Lake drainage area.

Much of the solids-related pollutants washed off the land surface upstream of Horn Pond would be intercepted by and accumulate in the Pond, and never reach the Aberjona River. Thus, evaluation of loadings to the lake for the entire watershed must consider the pollutant sinks in Horn Pond. However, it does not appear that the entire Horn Pond basin will contribute overflow in the near future, and its impact on the lake loadings was not assessed.

TABLE 3.9

AVERAGE ANNUAL POLLUTANT WASHOFF IN
UPPER MYSTIC LAKE WATERSHED
(LBS/YR)

<u>Subbasin</u>	<u>TSS</u>	<u>NO₃</u>	<u>TKN</u>	<u>PO₄</u>	<u>TP</u>	<u>BOD</u>
Mishawum	210,715	16,857	44,251	295	505	31,605
Barn	77,565	5,171	12,928	128	215	11,635
Sweetwater	464,100	4,641	10,828	1,083	1,720	69,615
Direct River	65,442	3,926	6,545	91	155	9,815
Muraco	48,651	1,621	2,703	39	65	7,300
Highland	47,119	3,141	2,618	131	185	7,065
Horn Pond	87,444	5,829	4,858	242	340	13,115

TABLE 3.10

TSS Washoff By Season
(lbs/season)

<u>Subbasin</u>	<u>Average Annual</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Mishawum	210,715	64,904	34,685	44,628	66,498
Barn	77,565	21,866	13,947	18,138	23,614
Sweetwater	464,100	132,256	86,881	107,632	137,331
Direct River	65,442	19,336	11,070	14,481	20,555
Muraco	48,651	14,140	8,589	10,983	14,939
Highland	47,119	13,675	8,298	10,652	14,494
Horn Pond	87,444	25,293	15,488	19,851	26,812

3-27a

TABLE 3.11

NITRATE-NITROGEN WASHOFF BY SEASON
(lbs/season)

<u>Subbasin</u>	<u>Average Annual</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Mishawum	16,857	5,192	2,775	3,570	5,320
Barn	5,171	1,458	930	1,209	1,574
Sweetwater	4,641	1,323	869	1,076	1,373
Direct River	3,926	1,160	664	869	1,233
Muraco	1,621	471	256	366	528
Highland	3,141	912	553	710	966
Horn Pond	5,829	1,686	1,033	1,323	1,787

TABLE 3.12

TKN WASHOFF BY SEASON
(lbs/season)

<u>Subbasin</u>	<u>Average Annual</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Mishawum	44,251	13,630	7,284	9,372	13,965
Barn	12,928	3,644	2,325	3,023	3,936
Sweetwater	10,828	3,086	2,027	2,511	3,204
Direct River	6,545	1,934	1,107	1,448	2,056
Muraco	2,703	786	477	610	830
Highland	2,618	760	461	592	805
Horn Pond	4,858	1,405	860	1,103	1,490

TABLE 3.13

ORTHOPHOSPHATE WASHOFF BY SEASON
(lbs/season)

<u>Subbasin</u>	<u>Average Annual</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Mishawum	295	91	49	62	93
Barn	128	36	23	30	39
Sweetwater	1,083	309	203	251	320
Direct River	91	27	15	20	29
Muraco	39	11	7	9	12
Highalnd	131	38	23	30	40
Horn Pond	242	70	43	55	74

TABLE 3.14

TOTAL PHOSPHORUS WASHOFF BY SEASON
(lb/Season)

<u>Subbasin</u>	<u>Average Annual</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Mishawum	505	156	84	106	159
Barn	215	60	39	50	66
Sweetwater	1,720	490	322	399	509
Direct River	155	46	26	34	49
Muraco	65	18	12	15	20
Highland	185	54	32	42	57
Horn Pond	340	99	60	78	103

TABLE 3.15

BOD WASHOFF BY SEASON
LOAD (lbs)

<u>STORM Subbasin</u>	<u>Average Annual</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Mishawum	31,605	9,735	5,202	6,694	9,974
Barn	11,635	3,278	2,092	2,721	3,544
Sweetwater	69,615	19,838	13,032	16,145	20,600
Direct River	9,815	2,900	1,660	2,172	3,083
Muraco	7,300	2,120	1,288	1,647	2,241
Highland	7,065	2,051	1,243	1,598	2,174
Horn Pond	13,115	3,794	2,323	2,978	4,022

Table 3.16

Total Pollutant Washoff For Horn Pond SubbasinWith Drainage Area Upstream of Pond Included

<u>Subbasin</u>	<u>Constituent</u>	<u>Average Annual</u>	<u>L O A D (lbs)</u>			
			<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
Horn Pond	TSS	497,780	143,980	88,170	113,000	152,630
	Orthophosphate	1,380	400	245	315	420
	Nitrate	33,180	9,600	5,880	7,530	10,170
	TKN	27,655	8,000	4,895	6,280	8,480
	Total P	1,935	564	341	444	586
	BOD	74,658	21,598	13,224	16,952	22,894

TABLE 3.17

Land Use And Estimated Runoff Coefficients
For Direct Lake Drainage

SUBBASIN	LAND USE			ESTIMATED RUNOFF COEFFICIENT*
	OPEN SPACE	RESIDENTIAL	COMMERCIAL/ INDUSTRIAL	
West Shore	70%	25%	5%	0.2
Boat Club	10%	60%	30%	0.29
Direct Lake	13%	63%	24%	0.27

*Based on runoff coefficients taken from Mystic Hydrology Study (CDM, 1981) for each land use.

3.8 Pollutant Load Computation for Direct Lake Drainage

STORM was not used to compute pollutant loadings from the area of direct lake drainage, as detailed wet weather water quality data were not available. However, the tributaries draining these areas were sampled several times by DEQE and those results used to compute pollutant loads.

Direct drainage to the lake was divided into three sub-basins: Boat Club, West Shore, and Direct Lake. The Boat Club sub-basin drains a significant portion of downtown Winchester, flows through several residential areas, and empties into Upper Mystic Lake near the Winchester Boat Club. West Shore sub-basin drains several residential areas, as well as a local golf course, before emptying into the west side of the lake. Direct Lake sub-basin is composed of all the remaining area not included in the other two sub-basins. There is no one discharge point for the Direct Lake sub-basin; rather, there are many point discharges located along the lake shore.

The DEQE water quality data were grouped by wet and dry weather. Mean concentrations for each constituent were calculated for each group. Because none of the sub-basins contained a streamflow gauge, average annual runoff volumes had to be computed separately. Runoff coefficients for each sub-basin were estimated based on existing land uses in each, as presented in Table 3.17. Based on runoff coefficients determined for each land use in the "Mystic Hydrology Study" (CDM, 1981), a total area-weighted runoff coefficient was calculated proportionally using the wet and dry weather data.

No water quality data were available for Direct Lake sub-basin. However, land use in Direct Lake is similar to land use in Boat Club sub-basin where data are available; therefore, mean wet and dry constituent concentrations for Boat Club were also used to calculate loads for the Direct Lake sub-basin except for phosphorus. Boat Club phosphorus concentrations were uncharacteristically high and not thought to be representative of the watershed. Thus, average wet and dry phosphorus concentrations for West Shore sub-basin were used to calculate phosphorus loads for the Direct Lake sub-basin. Table 3.18 presents the results of the analyses.

3.9 Summary

The simulation model STORM was applied to the Upper Mystic Lake watershed to compute the quantity and quality of urban runoff. Field data collected during the course of the study were used to compute the parameter values during the model calibration. Since the receiving water of concern is a large lake, the average annual pollutant loads are important. The model was calibrated to predict the average loads, and should not be construed as an individual storm simulation. sub-basin loading values for TSS, BOD, TKN, TP, and orthophosphate were computed.

One of the original objectives was to determine whether the data collected are transferrable to other watersheds. The end-of-pipe data can be used as representative of residential and light industrial or commercial areas, but the instream data should be applied with care. The Sweetwater and Mishawum sub-basins contribute uncharacteristically high concentrations of certain constituents. If the instream data are to be used in a transfer application, the effects of high ammonia levels at Mishawum and sewage discharges at Sweetwater should be screened out. After screening, the data should be representative of areas with mixed residential/commercial land uses.

CHAPTER 4

ANALYSIS OF THE IMPACTS OF STORMWATER DISCHARGES ON THE ABERJONA RIVER

4.1 Introduction

Once pollutants are washed off the land surface and routed to receiving waters, instream physical and biochemical processes act to transport or remove the various constituents. Advection, deposition, dispersion, natural decay, and plant uptake are major physical phenomena to consider when assessing the fate of pollutants introduced into receiving waters.

This Chapter describes the methods used in and the conclusions drawn from the analysis of the effects of urban runoff on the Aberjona River. Section 4.1 describes the objectives of the analysis, the constituents that were considered, and the water quality standards and goals for the receiving waters as defined by the NURP program. In Section 4.2 the receiving water model and relation to the STORM simulation results are described. The available data base describing both historical and present-day conditions in the Aberjona River is presented in Section 4.3. In Section 4.4 application of the Receiving Water Quality Model (RWQM) is discussed. Principal input parameters, dominant instream reaction mechanisms, and calibration results for both the hydrology and water quality components are presented. Finally, predictive simulations to estimate annual and seasonal pollutant loads to Upper Mystic lake using RWQM are described. This section also includes identification of critical loading areas, feasible control strategies and required pollutant removal levels.

4.1.1 Objectives of Analysis

The objectives of the modeling analyses in general, and the RWQM analysis in particular, are two-fold:

1. To quantify seasonal and annual pollutant loads to Upper Mystic Lake, and
2. To test feasible control measures to attenuate pollutant concentrations and/or mitigate the effects of urban runoff on lake quality.

Pollutant loadings to Upper Mystic Lake can be broken down into two components: loads from dry-weather flow and loads from urban runoff. The STORM model analysis provided estimates of the amount of pollutant washed off the land surface during wet periods, and results of the dry-weather sampling program undertaken by the DEQE and MRWA were used to quantify pollutant concentrations in the baseflow. The RWQM simulates both dry and wet weather flows and pollutant dynamics.

Once a reasonable estimate of pollutant mass entering the lake on an annual basis is determined, the efficacy of various control strategies can be assessed. The simulation can be used to determine the extent of application required for a given control to secure a certain pollutant level at various points in the system and to determine the optimal placement of a control within the watershed. Desired pollutant levels in the lake are directly related to State water quality standards and the local goals defined by the NURP program. These goals include:

1. Maintaining Class B water quality standards in the Aberjona River and Upper Mystic Lake;
2. Minimizing the eutrophication potential of the lake;
3. Maintaining acceptable coliform levels at Sandy Beach; and
4. Maintaining a warm water fishery and improving quality to that required for a cold water fishery, if possible.

Given these conditions, and the fact that Class B standards for DO and pH are not violated in the Aberjona or the epilimnion of the lake in general, the principal constituents of concern in the Upper Mystic Lake watershed are plant nutrients and coliform organisms. For most lakes in the oligotrophic, mesotrophic, or early eutrophic stages, the factor that limits growth is one of three major nutrients: carbon, nitrogen, or phosphorus. Rather than try to control numerous nutrients, it is more efficient to control one nutrient - the nutrient least available relative to the growth requirements of algae and other plants. Carbon is plentiful in virtually all watersheds and as a result, nitrogen and phosphorus are the nutrients that most frequently limit plant growth. By measuring the amount of nitrogen and phosphorus immediately available to the biological system (ammonia and nitrate-nitrogen and phosphorus), one can calculate the ratio of nitrogen to phosphorus (N/P). This ratio indicates which nutrient would be fully consumed first by the lake's biological system, and thus, would limit further growth. In general, above a nitrogen to phosphorus ratio of 12:1, a lake can be considered phosphorus limited; below 12:1, it can be considered nitrogen limited.

Based on nutrient data collected by the MDC between 1974 and 1980, Upper Mystic Lake is phosphorus limited. Data collected during the NURP study and by MDWPC collaborate this finding. Statistical analyses of 31 water quality samples taken during that time show the median nitrogen to phosphorus ratio to be 34:1, well above the necessary value. The mean N/P ratio is 101:1 with a standard deviation of 107. Thus, there is plenty of nitrogen available for plant growth in the lake, and the most effective eutrophication management strategy would be to control phosphorus loadings. Consequently, phosphorus, was selected for simulation with RWQM.

The nature of the water quality problems in the Upper Mystic Lake watershed are such that the analyses should consider long-term pollutant loadings to the lake. Eutrophication is a gradual process that occurs as nutrient-induced plant growth accelerates over the course of many years. Thus, average annual phosphorus loads give a better indication of trends in lake trophic status than isolated, short-term storm loadings.

Total coliform was included in the analysis to ascertain whether bacteria levels in the Aberjona River pose a threat to recreational use, specifically swimming at Sandy Beach. Total coliform was used rather than fecal, as the wet weather data for total coliforms collected during this study are much more complete and applicable to the analysis. The wet weather data for fecal coliform were scarce and inconsistent (often greater than total coliforms), and were therefore insufficient for characterization of urban runoff concentrations. While total coliforms are not pathogenic, they are indicative of the presence of some pathogens, and Class B water quality standards exist for total coliform. The major sources of coliform in the watershed are the combined sewer networks in the Sweetwater Brook subbasin and Winchester and urban runoff. Instream simulation allowed reasonable quantification of bacterial transport and the potential threat coliform sources pose to Sandy Beach.

In the Upper Mystic Lake watershed, and for urban runoff in general, coliform levels show great variation from storm to storm. These variations can be as much as two orders of magnitude. Analyzing results from individual storms makes it difficult to compute die-off rates, as coliforms were measured the day after storm events. Thus, storm-specific data were aggregated in an attempt to characterize the long-term coliform behavior in the Aberjona and average annual and maximum loadings to the lake. The intent of the analysis was to indicate what coliform levels can be expected to occur on the average in the lake during the swimming season.

In addition to coliforms and phosphorus, loadings of heavy metals and BOD to the lake were estimated. The values were based on scarce sampling results. These constituents were not sampled frequently during the field program, and as a result, the data necessary to simulate their transport in the Aberjona were not available.

4.2 Analysis Methods

STORM simulates the washoff and outflow of pollutants from individual watersheds over long periods of time on an hourly time step. While long-term washoff estimates may aid in the planning of pollution controls, by itself STORM does not predict the impacts of subbasin outflows on receiving water quality. RWQM, when linked with the time history of storm and dry-weather flows generated by STORM, provides such a capability.

RWQM operates at hourly or multiple-hourly time steps, simulating the one-dimensional transport and instream transformation of up to four water quality constituents in freshwater stream networks. Long-term simulation of water quality conditions allows analysis of many combinations of hydrologic and pollutant loading conditions, unlike single event or low flow "critical" condition simulation. The STORM-RWQM combination permits the user to undertake planning level analyses of water quality impacts of both structural and non-structural control strategies.

RWQM simulates time-varying hydraulic and water quality conditions by using the conservation of mass principle. Simply stated, for a finite length of stream, the mass inflow minus the mass outflow during a discrete time period must equal the change in mass storage during that same time interval, or expressed symbolically:

$$\frac{\Delta M}{\Delta t} = I - O \pm S \quad (4.1)$$

where: ΔM = change in mass storage
 Δt = time period duration
 I = mass inflow rate
 O = mass outflow rate
 S = mass input rate from sources and sinks

The model is applied by dividing the river into a series of segments. The volume of water in each stream segment is determined by the depth of flow in a segment, which is directly related to the flow rate.

Flow rates are calculated using one of three methods:

1. Manning's equation where the user specifies roughness values, slope, and channel width;
2. Kinematic wave equation where the user specifies geometry and friction-dependent parameters; or
3. Cross sectional area versus flow tables.

After the hydraulic conditions at a time step have been computed, pollutant concentrations are calculated based on:

$$M_p = M_w \cdot C_p \quad (4.2)$$

where: M_p = pollutant mass

M_w = mass or volume of water

C_p = pollutant concentration

Incoming pollutant mass is provided by STORM. STORM generates hourly summaries of pollutant mass (in pounds) and flow (in cfs). Results for each STORM subbasin are then linked to RWQM and represent the wet-weather pollutant loads from each area. STORM-generated pollutant mass can be input as a point source, or distributed laterally along the stream as a non-point source, whichever is more representative of field conditions.

4.2.1 Physical Instream Phenomena

The principal physical mechanisms simulated by RWQM are advection, deposition, decay, and die-off. Advection is that transport which results from fluid motion. Settling of constituents is simulated as a volumetric sink or a first-order removal. First-order decay or dieoff rates are specified for non-conservative substances. Longitudinal dispersion is not simulated, however, but this should not be a problem in the relatively well-mixed, swift-flowing Aberjona.

RWQM results include minimum, maximum and, more importantly, long-term average concentrations of a given constituent over the simulation period. In addition, percentile curves for each constituent, which show the frequency distribution of water quality parameters over time can be computed at any user-selected location. When evaluating the effects of intermittent, storm-generated loadings, the percentile curves are an important statistical output from RWQM, since they demonstrate the frequency distribution of water quality levels, streamflows, and stream temperatures. Table 4.1 presents a sample percentile curve at the USGS gauge. Other curves are included in Appendix C. Finally, pollutographs (constituent concentration vs time) plots can be generated by RWQM at user-selected locations. Because long-term average constituent loadings are being assessed, the water quality characteristics at any particular hour are not important to the analysis. Consequently, pollutographs were not developed for the Aberjona application.

TABLE 4.1

PERCENTILE CURVE AT USGS GAUGE

T E M P E R A T U R E		P H O S P H O R U S		T O T A L C O L I F O R M	
Percentile Limits	Frequency (% of time)	Percentile Limits	Frequency (% of time)	Percentile Limits	Frequency (% of time)
Below 32° F.	0	Below 0.0 mg/l	0.0	Below 0 MPN/100 ml	0
Below 38° F.	0	Below 0.05 mg/l	1.0	Below 1,000 MPN/100 ml	80
Below 44° F.	0	Below 0.10 mg/l	95	Below 2,000 MPN/100 ml	90
Below 50° F.	0.5	Below 0.15 mg/l	100	Below 3,000 MPN/100 ml	95
Below 56° F.	16	Below 0.20 mg/l	100	Below 4,000 MPN/100 ml	99
Below 62° F.	34	Below 0.25 mg/l	100	Below 5,000 MPN/100 ml	100
Below 68° F.	70	Below 0.30 mg/l	100	Below 6,000 MPN/100 ml	100
Below 74° F.	100	Below 0.35 mg/l	100	Below 7,000 MPN/100 ml	100
Below 80° F.	100	Below 0.40 mg/l	100	Below 8,000 MPN/100 ml	100
Below 86° F.	100	Below 0.45 mg/l	100	Below 9,000 MPN/100 ml	100
Below 92° F.	100	Below 0.50 mg/l	100	Below 10,000 MPN/100 ml	100

Note: Results based on 6 month RQM simulation (May-Oct)

4.3 Data Base

Several sources of data were used in the receiving water quality analysis. A summary of coliform and phosphorus concentrations used in the dry weather flow simulation is presented in Table 4.2. Prior sampling efforts undertaken by the MDC were reviewed to arrive at reasonable dry-weather flow concentrations for coliform (MDC 1979, 1980). The MDC sampled total coliform at Mishawum Road, Montvale Avenue, and the USGS gauge each month for those two years. Based on these data, dry-weather total coliform levels of 2000 MPN/100 ml were assigned at Mishawum Road and Montvale Avenue, and 3000 MPN/100 ml at the gauge. Dry-weather coliform data collected by DEQE were also reviewed for consistency with MDC data. Both sets of data were in agreement, although geometric means at the gauge were lower for the DEQE data. Because the DEQE means were calculated from between one and six samples, dry-weather coliform levels were assigned based on the larger MDC sampling data base.

Dry-weather phosphorus concentrations were taken from sampling data collected by DEQE and MRWA. DEQE obtained dry-weather phosphorus concentrations at Mishawum Road, Olympia Street, Salem Street, Mill Street, Washington Street, and the gauge. MRWA data are available for Mishawum Road and the gauge only. The MRWA average phosphorus concentrations are based on many more water quality samples than the DEQE data (78 dry-weather samples versus 4 for the gauge). Thus, dry-weather phosphorus concentrations of 0.04 mg/l and 0.07 mg/l (Table 4.2) were assigned at Mishawum Road and the gauge, respectively based on the MRWA data while phosphorus concentrations at the remaining sites were based on DEQE data. These latter values included 0.04 mg/l at Olympia Street, 0.05 mg/l at Salem Street, 0.06 mg/l at Mill Street, and 0.13 mg/l at Washington Street. Wet-weather data were taken from the STORM model results which were presented in Sections 2 and 3. The Mystic River Hydrology Study (CDM, 1981) was the source of many physical data including channel widths and depths and stream bed slopes.

Finally, dye tracer studies conducted by the USGS were used to compute travel times between segments. Since many of the instream physical phenomena are directly linked to the volume of water in a given segment at a given time, it is imperative that runoff hydrographs are accurately routed through the hydraulic network. Comparing known travel times measured by the USGS with RWQM-simulated travel times effectively checked the validity of the computed hydraulics, and provided for greater accuracy in estimating rates of dieoff and deposition, as runoff and associated pollutants were routed through the receiving waters.

TABLE 4.2

CONTINUOUS DRY WEATHER TOTAL PHOSPHORUS AND TOTAL COLIFORM CONCENTRATIONS

1) MDC Sampling Data, 1979 to 1980:

<u>Location</u>	<u>Total Coliform Concentration* (MPN/100 ml)</u>	<u>Total Phosphorus Concentration (mg/l)</u>
Mishawum Road	2,000	0.04
Montvale Avenue	1,700	0.05
USGS Gauge	3,000	0.08

2) MRWA Volunteer Data, 1980 to 1981:

Mishawum Road	Not Sampled	0.04
USGS Gauge	Not Sampled	0.07

3) DEQE Sampling Data, 1981:

Mishawum Road	1,300	0.07
Olympia Street	650	0.04
Salem Street	6,000	0.05
Mill Street	1,600	0.06
Washington Street	47,000	0.13
USGS Gauge	1,000	0.05

* Geometric Mean

4.4 RWQM Application

4.4.1 Basin Segmentation

The Aberjona River was divided into six 0.8 mile computational segments. Segments were established in areas of similar hydrologic characteristics and at locations of major inflows. Figure 4.1 depicts the segmentation of the mainstem Aberjona, and Table 4.3 summarizes key landmarks by river mile.

The uppermost reach (RM 5.3 to 4.5) is characterized by a channel between ten and twenty feet wide with moderately dense vegetation in the channel and overbank areas. Two tributaries (Barn Trib and another unnamed trib) empty into the Aberjona in this reach. In the next reach (RM 4.5 to 3.7), the channel widens out to between twenty five and forty feet. Vegetation is thick, especially in two large marshy areas marked by a sinuous channel and low velocities. From RM 3.7 to 2.9, the Aberjona channel narrows to about ten feet and is obstructed along much of its course by moderately thick vegetation and man-made debris. The Sweetwater Brook confluence is located at RM 3.3. A dam and pond are also found in this reach (RM 2.9). In the next reach (RM 2.9 to 2.1), channel obstructions greatly diminish. Overbank roughness also decreases. Several large impoundments are located in the next reach (RM 2.1 to 1.3). Slow velocities, wide channels and light to moderately thick brush are characteristic. Solids settling is thought to occur in the impoundments. In the most downstream reach (RM 1.3 to 0.5), the Aberjona flows into a set of culverts beneath the Winchester Athletic fields, opens up into a well-defined channel and then into two small ponds behind the Winchester Town Hall. Horn Pond Brook empties into the Aberjona at RM 1.1. Immediately upstream and downstream of the gauge, the channel is well-defined bordered by moderately thick woods and brush.

The seven STORM subbasins (delineated and described in Chapter 3) were linked to RWQM as both point and distributed sources, as they occur in the field. Figure 4.2 is a schematic describing the linking network. Except for Direct Aberjona and Muraco, all subbasins were simulated as point source inflows. Linking Aberjona and Muraco as distributed source inflows is more appropriate, as neither subbasin contains a well-defined stream; rather, each contains storm drainage networks with outlets that discharge at several locations along the river.

Simulation of the Aberjona was begun at river mile 0.5 (USGS gauge) and not at river mile 0.0 (inlet to Upper Mystic Lake), because little water quality and flow data were available at the inlet. Years of water quality data and flow records were available at the gauge, greatly aiding calibration efforts.

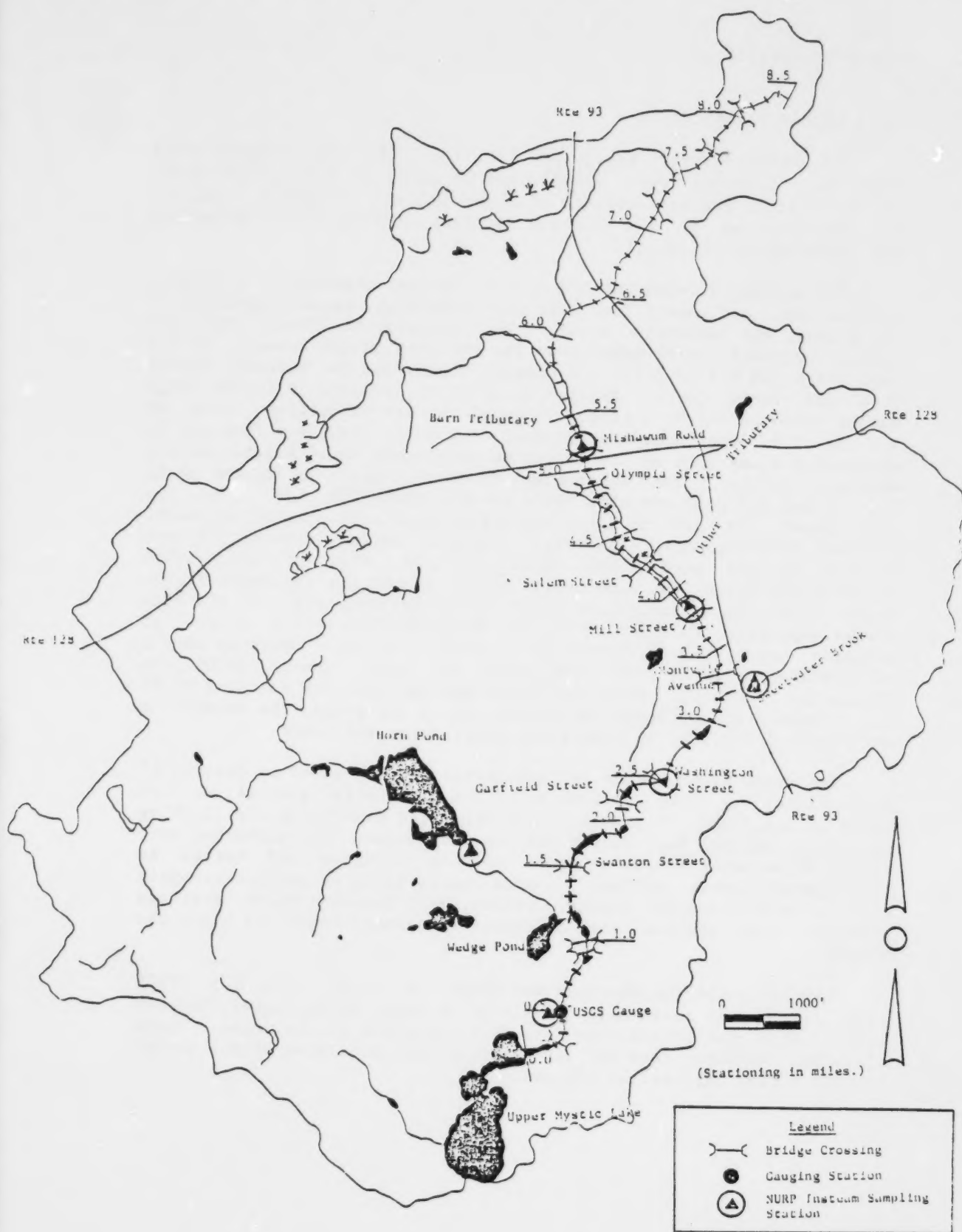


Figure 4.1

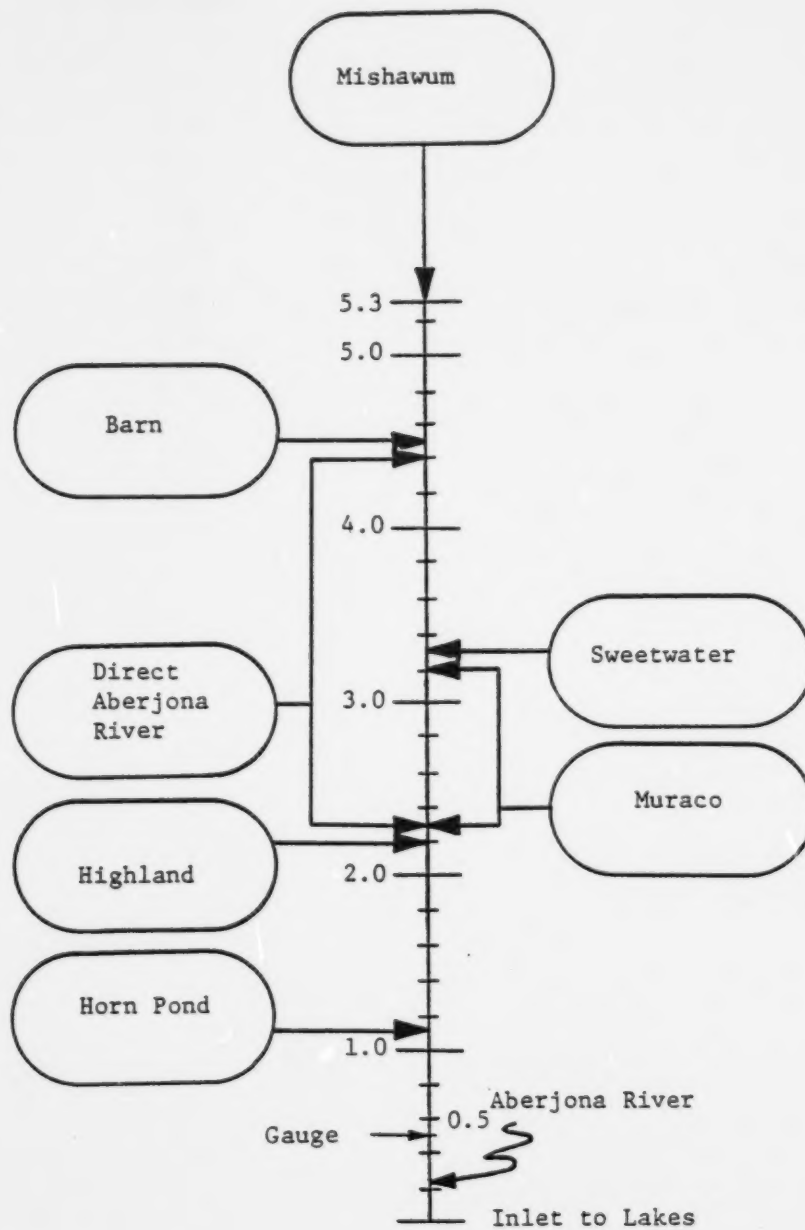
TABLE 4.3

KEY LOCATIONS IN THE ABERJONA BASIN

<u>Location Description</u>	<u>River Mile</u>
Inlet to Upper Mystic Lake	0.0
USGS Gauge	0.5
Swanton St.	1.5
Garfield St.	2.1
Washington St.	2.5
Sweetwater Brook Confluence	3.3
Montvale	3.4
Mill Street	3.8
Salem St.	4.3
Olympia St.	4.9
Mishawum Rd.	5.3

Figure 4.2

LINKING OF STORM SUBBASINS WITH RWQM



4.4.2 Inputs to the System

Hydraulic routing from segment to segment was computed using Manning's equation for open channel flow. For each segment, a channel slope, channel width, and roughness coefficient was specified. These values are shown in Table 4.4. Channel slopes and cross section data were taken from the Mystic Hydrology Study prepared by CDM (1981). Results were checked against time of travel studies conducted by the USGS and historic flow measurements at the gauge to assure reasonable results.

In the USGS time of travel studies, a slug of dye was placed at Mishawum Road on the Aberjona River and maximum concentrations and the times of travel were measured at various downstream locations, including the Washington Street crossing and the gauge. Travel times were highly dependent on flow conditions in the Aberjona. For example, when flow at the gauge is 3 cfs, it takes about 25 hours for dye to travel from Mishawum Road to Washington Street. At 45 cfs, it takes 8 hours to travel from Mishawum Road to Washington Street and 17 hours from Mishawum Road to the gauge.

Because many of the instream biological processes are dependent on the volume of water in a segment at a given time, every effort was made to duplicate these hydraulic conditions as accurately as possible. Roughness coefficients became the mechanism by which the dye study conditions were matched.

Normally associated with friction losses only, Manning's n-values in the RWQM analysis were used to represent other losses as well. Because RWQM does not simulate large storage areas such as ponds, lakes and other run-of-river impoundments, or backwater effects caused by constricted culverts and bridges, Manning's n-values were used herein to incorporate the effects of those hydraulic conditions. Since average cross section width includes both channel and overbank portions, the roughness coefficient represents average conditions across the entire cross-section. Thus, n-values were used to represent all losses occurring along the stream--not just losses due to channel roughness, causing the n-values in Table 4.4 to be higher than normal.

The higher n-values resulted in good agreement between computed travel times and those observed by USGS during the dye studies. Table 4.5 presents the results of the two efforts. The travel time to the gauge at 3 cfs was the only condition that could not be duplicated, and that is an extreme low-flow event. The 7-day 10 year low flow for the Aberjona River is approximately 1.5 cfs (CDM, 1980). The travel time to Washington Street was successfully duplicated, but the series of impoundments between Washington Street and the gauge are too hydraulically complex to be handled at such a low flow. Eddies and macrophytes may have slowed the velocities in the channel and impoundments thereby causing the extended travel time observed by the USGS. In any event, since 89% flows will exceed 3 cfs (based on USGS gauge records), the inability to match travel time for this drought condition is not a great concern.

TABLE 4.4

HYDRAULIC PARAMETERS USED IN RWQM

<u>River Mile</u>	<u>Channel Slope (ft/ft)</u>	<u>Roughness Coefficients</u>	<u>Width of Channel (ft)</u>
4.9	0.004	0.45	15.0
3.7	0.001	0.5	17.0
2.5	0.002	0.5	25.0
0.9	0.002	0.35	35.0
0.5	0.001	0.4	35.0

TABLE 4.5

USGS FIELD-MEASURED VERSUS RWQM-SIMULATED TRAVEL TIMES

Location	Field-Measured Travel Times ¹ (hours)		CDM Simulated Travel Times ² (hours)	
	Q=3 cfs	Q=45 cfs	Q=3 cfs	Q=45 cfs
From Mishawum Road to Washington Street	25	8	24	7
From Mishawum Road to USGS Gauge	132	17	45	19

¹From Dye Tracer Studies conducted by USGS

²RWQM Simulation

4.4.3 Constituents of Concern

Phosphorus and total coliform were simulated in the Aberjona using RWQM. These constituents are the principal indicators of water quality problems, as manifested in potential eutrophication and recreation inhibition. Other constituents (suspended solids, BOD, and nitrogen) simulated with STORM were not simulated with RWQM as the instream sources and sinks were not as well defined or important in evaluating the water quality problems. Phosphorus sinks include uptake and physical sinking. The impoundment immediately below Sweetwater Brook and the series of ponds between Washington Street and the gauge are the principal sinks. Plant uptake by rooted plants was not simulated as such, but was included with the sedimentation process and simulated as a constant rate volumetric sink. Nutrient uptake by floating plants was not simulated per se, as those plants and the nutrients they bind up will enter the lake directly. First-order coliform dieoff (decay) rates were also specified.

4.4.4 Hydrology Calibration

Calibration of the hydrology component was carried out using both dry and wet weather flows. As stated previously, the average annual flow at the gauge of 27 cfs is approximately 13 cfs baseflow and 14 cfs runoff. Baseflow was simulated as a continuous dry weather source with contributions from each of the seven STORM subbasins. The total of 13 cfs was apportioned to each subbasin on the basis of the size of drainage area, as displayed in Table 4.6. Incrementally adding baseflow in this manner generated a smooth, reasonable transition progressing from Mishawum Road to the gauge.

Wet-weather flows were obtained from STORM results for each of the seven subbasins. For the hydrology calibration, a six month period with representative rainfall (May to October, 1973) was simulated. While this period is shorter than the STORM simulation period, it is representative of the normal flow conditions, and excellent for scaling to average annual loads. Test simulations over longer periods showed that the six month period selected is adequate for annual load estimation. For this 180-day simulation period, an average streamflow of 22.6 cfs was obtained. USGS gauge records for the Aberjona River during that time frame show an average flow of 23.6 cfs. Because average annual loads are being assessed, the use of typical rainfall is appropriate. Simulated streamflow was within 96% of measured streamflow. Given that STORM-generated hydrographs generally have higher peaks and recede more quickly than hydrographs observed at the gauge, the streamflows generated by RWQM are constrained to a certain degree by the accuracy of the STORM results. With this in mind, the hydrology component RWQM was assumed sufficiently calibrated given model constraints, and the next step became one of calibrating the water quality component.

TABLE 4.6

CONTRIBUTION TO BASEFLOW BY STORM SUBBASIN

<u>STORM Subbasin</u>	<u>Drainage Area (acres)</u>	<u>Baseflow Contribution (cfs)</u>
Mishawum	4,021	4.6
Barn	1,800	2.0
Sweetwater	1,450	1.6
Direct Aberjona	1,650	1.8
Muraco	620	0.7
Highland	620	0.7
Horn Pond	1,145	<u>1.6</u>
Total:		13 cfs

4.4.5 Water Quality Calibration

Using a similar procedure to that used in the hydrology calibration, the water quality calibration was broken into dry and wet weather components. The 13 cfs dry-weather flow was assigned a constant phosphorus concentration consistent with water quality data collected by DEQE and MRWA during dry weather periods. These concentrations were 0.04 mg/l and 0.07 mg/l at Mishawum Road and the gauge, respectively. Therefore, a constant phosphorus concentration of 0.04 mg/l was assigned to baseflows for subbasins in the upstream reaches (Mishawum, Barn, Direct River) and 0.07 mg/l to baseflows in the remaining subbasins. Wet-weather phosphorus concentrations were computed using STORM, and were taken from results stored on computer files.

Baseflow coliform concentrations were assigned to each subbasin based on water quality data collected by the MDC in 1979 and 1980, which showed total coliform levels approach 1700 MPN/100 ml and 3000 MPN/100 ml at Montvale Avenue and the gauge, respectively, during dry weather periods.

Wet weather coliform levels were assigned in a slightly different manner. Coliform organisms were not expressly included in the STORM analysis due to the sporadic results of the sampling program. Water quality data collected by EDP show average wet weather coliform levels to approach 10,000 MPN/100 ml for pure urban runoff in the Aberjona watershed. Sweetwater Brook counts were on the order of 3,000,000 MPN/100 ml. Coliforms were simulated by assigning a constant concentration to urban runoff, based on observed field data. The Sweetwater Brook basin was assigned a separate value more representative of the values observed there. This approach is good for simulating long-term average loads, which is the best that can be accomplished considering the nature of urban runoff and the existing data.

4.4.6 Natural Pollutant Removal Mechanisms

During instream transport, pollutants are removed by natural mechanisms. Two such mechanisms considered in the RWQM analysis were solids deposition and bacterial die-off.

Comparisons between STORM-generated loads and loads estimated from field data at Washington Street and the gauge reveal that there are significant pollutant sinks to be incorporated into the receiving water quality analysis. STORM-generated phosphorus loads match measured loads in the Sweetwater subbasin, but are too high at Washington Street when all loads above that point are summed. STORM-generated TSS and phosphate loads for the watershed above the gauge are also higher than observed in the field.

There is further evidence that deposition occurs between Washington Street and the gauge. Based on data from the seven sampled storms, 66% of the phosphate at Washington Street is in particulate form and the rest dissolved. However, downstream at the gauge, the particulate fraction drops to 57%. Since only the particulate portion can physically settle out of suspension, the drop in the particulate proportion is attributed to the settling of solid materials. The soluble fraction is probably removed to some extent during plant growth.

Based on water quality data collected by EDP, and results of the STORM analysis (Chapter 3), several areas have been identified as possibly acting as pollutant "sinks", or natural sedimentation basins. These areas are:

1. The meandering channel and swampy area between the Mill Street and Olympia Avenue river crossings (River Mile 3.8 to 4.9),
2. The dam and pond upstream of the Washington Street crossing and downstream of the Sweetwater Brook confluence (River Mile 2.9 to 3.0),
3. The series of ponds/impoundments between the Swanton and Washington Street crossings (River Mile 1.5 to 2.2), and
4. Judkins and Mill Ponds behind the Winchester Town Hall (River Mile 0.8 to 1.1).

The effects of each area were estimated by assigning volumetric sink values to the appropriate model reaches. The values were assigned based on the potential for pollutant removal by sedimentation, which is a function of detention time and depth. The results of the calibration using the assigned parameter values are presented in the next sub-section.

For coliform organisms natural mortality effects were incorporated into the analysis using a first-order dieoff rate. This rate is a calibration parameter, which was adjusted to match observed coliform concentrations in the Aberjona. Sensitivity analyses were conducted to assess the effects of varying coliform dieoff rates. A dieoff rate of 1.1/day resulted in a reasonable duplication of observed coliform levels at the gauge. This calibrated dieoff rate was used in all subsequent simulations. Results of sensitivity analyses conducted to determine the acceptable dieoff rate are presented in Section 4.4.8.

4.4.7 Calibration Results

Table 4.7 presents two sets of water quality data:

1. Mean phosphorus and geometric mean coliform concentrations at various locations in the Aberjona based on samples taken by EDP, and
2. Simulated average concentrations for both constituents based on RWQM calibration results.

The first set represents actual concentrations measured in the field for seven storms; the second set was generated by RWQM based on a six-month simulation (May 1 to October 30, 1973) of typical precipitation.

To achieve a successful calibration, volumetric sinks were placed at three locations:

1. SINK 1: The meandering channel between Salem and Mill Streets (River Mile 3.9 to 4.2),
2. SINK 2: The pond upstream of Washington Street and downstream of the Sweetwater Brook confluence (River Mile 2.6 to 3.0), and
3. SINK 3: The series of impoundments between the Swanton and Garfield Street crossings (River Mile 1.5 to 2.2).

Figure 4.3 presents RWQM-generated average phosphorus concentrations, as well as field-measured dry and wet weather concentrations, as a river profile. Long-term average concentrations approached dry-weather concentrations. This is not unexpected as wet-weather events of short duration are damped out and baseflow contribution, over the course of a year, becomes significant.

Table 4.8 presents a summary of the amount of phosphorus washed off the land surface, amount settled out, and amount reaching the lake. In total, 2,850 pounds of phosphorus are contributed to Upper Mystic Lake by urban runoff from the Aberjona annually. Dry-weather flow in the Aberjona contributes another 1,790 pounds of total phosphorus. Phosphorus contributions from lake bottom sediments have been estimated at 750 pounds per year. Groundwater load is estimated to equal 30 pounds for a total annual loading of approximately 6,450 pounds.

While phosphorus concentrations averaged 0.07 mg/l at the gauge, they ranged from 0.06 to 0.38 mg/l for the simulation period. Further upstream at the second Washington Street crossing, phosphorus concentrations ranged from 0.06 to 0.40 mg/l. The higher range at this location is a result of inflows from Sweetwater Brook, a major phosphorus contributor due to CSOs.

TABLE 4.7

RWQM CALIBRATION RESULTS

L O C A T I O N	Average Concentrations from Field-Measured Data				Average Concentrations from RWQM Simulation	
	Phosphorus (mg/l)		Coliform (MPN/100 ml)		Phosphorus (mg/l)	Coliform (MPN/100 ml)
	Wet	Dry	Wet	Dry		
Mishawum Road	0.09	0.04	1,000	1,700	0.04	2,200
Mill Street	0.10	0.06	-	-	0.06	1,700
Washington Street	0.30	0.13	-	-	0.10	3,500
USGS Gauge	0.10	0.07	1,000	3,000	0.08	3,100

Figure 4.3

FIELD - MEASURED VS RWQM - SIMULATED TOTAL PHOSPHORUS CONCENTRATIONS

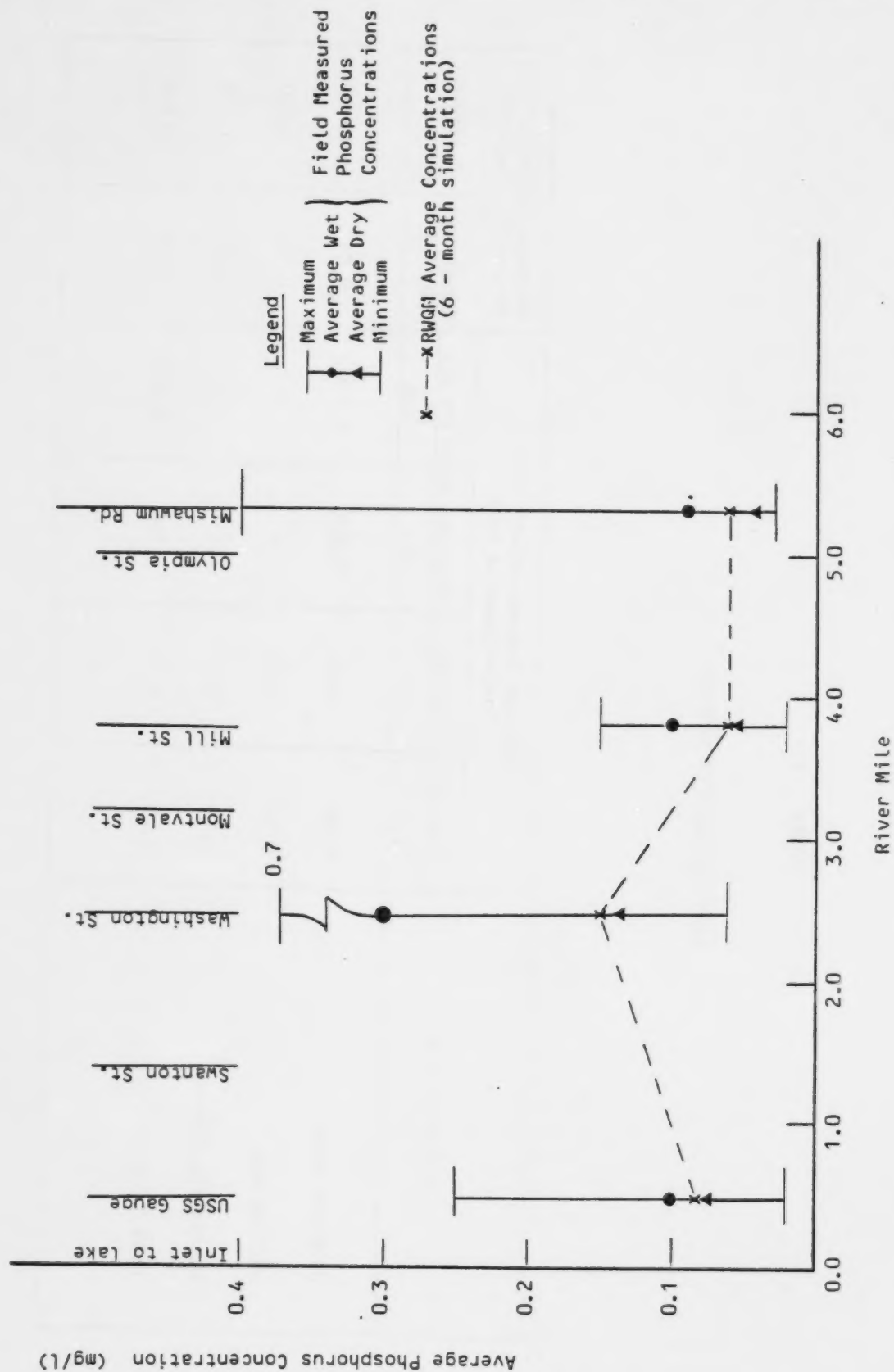


TABLE 4.8

ANNUAL TOTAL PHOSPHORUS LOADING TO LAKE
(lb/year)

o Washed Off Land Surface of Aberjona Watershed	3,190
Settled Out in:	
Sink No. 1	20
Sink No. 2	120
Sink No. 3	<u>200</u>
Load From Urban Runoff	2,850
Load From Baseflow	<u>1,790</u>
o Total Load From Aberjona River	4,640
Urban Runoff From Direct Drainage to Lake:	
Golf Subbasin	65
Yacht Subbasin	345
Direct Lake Subbasin	<u>50</u>
	460
Baseflow Load From Direct Drainage to Lake:	
Golf Subbasin	30
Yacht Subbasin	520
Direct Lake	20
o Total Load From Direct Drainage to Lake:	1,030
o Groundwater Load (0.5 cfs $\times$ 0.03 mg/l):	30
o Load From Lake Bottom Sediments:	<u>750</u>
o Total Load to Lake (lb/year):	6,450

Computed coliform concentrations averaged 3330 MPN/100 ml at the gauge, ranging from 690 MPN/100 ml to 462,000 MPN/100 ml over the simulation period. The effect of Sweetwater Brook CSOs on Aberjona River water quality is evident. Coliform levels immediately downstream of the Sweetwater confluence (River Mile 3.0) range from 1200 MPN/100 ml to 1,800,000 MPN/100 ml, compared with 1300 to 9000 MPN/100 ml immediately upstream of Sweetwater Brook.

The calibration was achieved using a first order coliform dieoff rate (k) of 1.1/day (base e). This value falls within the generally accepted range of 1.0 to 2.0.

4.4.8 Sensitivity Analyses

Sensitivity analyses were conducted to assess the effects of varying dry and wet weather coliform loads, Manning's n -values, coliform dieoff rates, and the magnitudes of the volumetric sinks. Table 4.9 presents the results of varying the coliform dieoff rate. The calibrated value of 3,000 MPN/100 ml at the gauge was attained with a dieoff rate of 1.1/day.

Table 4.10 presents the changes that occur in average, minimum, and maximum coliform levels at the gauge by increasing and decreasing both baseflow and urban runoff coliform concentrations by 50 percent. As expected, changes in baseflow concentrations resulted in greater changes in geometric averages than maximum levels. Over the long simulation periods used in this analysis, geometric averages tend to approach the dry weather concentrations, as there are many more dry hours than wet. Varying urban runoff coliform concentrations, on the other hand, resulted in greater variations in maximum coliform levels, which are the result of overflows in Sweetwater Brook. Minimum coliform concentrations were dependent entirely on baseflow concentrations.

As described in Section 4.4.2, Manning's n -values represent all energy losses along the river reach, not just friction losses. N -values were manipulated to match travel times determined in the USGS dye tracer studies. First, a constant n -value of 0.45 was specified for the entire river; n -values were subsequently varied by river reach to account for variations in channel and overbank roughness as presented in Table 4.4. Both sensitivity runs duplicated conditions determined in the dye studies, save for the extreme low-flow conditions. It is apparent that either method will secure desired results: a constant value can be specified or values can be varied as long as the average value along the entire river approaches 0.45. The calibrated results were achieved with different values in the upper and lower reaches of the river. The higher n -values used in the upper reaches (0.5) tended to balance out the lower values (0.35) so that an average value of 0.45 was attained. The use of varying n -values was deemed more appropriate so that local roughness conditions within each reach could be better simulated.

Table 4.9

RWQM Sensitivity to Varying Coliform Dieoff Rates

<u>Dieoff Rate (1/day)</u>	<u>Geometric Mean of Coliform Levels @ USGS Gauge (MPN/100 ml)</u>
1.0	3,400
1.5	2,200
1.25	2,700
1.1	3,100

Long term average at gauge
Based on MDC Data: 3,000 MPN/100 ml

$k = 1.1/\text{day}$ (calibrated value)

TABLE 4.10

SENSITIVITY ANALYSIS FOR DRY AND
WET WEATHER COLIFORM CONCENTRATIONS

S E N S I T I V I T Y R U N S	Coliform Levels @ USGS Gauge (MPN/100 ml)		
	Geometric Average	Minimum	Maximum
o Base Case	3,100	700	480,000
o 50% Reduction in Dry-Weather Coliform Concentrations	1,800	350	474,000
o 50% Increase in Dry-Weather Coliform Concentrations	5,300	1,440	486,000
o 50% Reduction in Urban Runoff Coliform Concentrations	2,600	700	246,000
o 50% Increase in Urban Runoff Coliform Concentrations	3,700	700	923,000

Finally, the magnitudes of the three sinks were varied to determine the sensitivity of long-term average phosphorus concentrations. Table 4.11 presents the results of assigning different values for each of the volumetric sinks. Variations in the magnitude of the third sink resulted in the least change in phosphorus concentration. The lack of sensitivity of the third sink is directly related to its positioning. The third sink extends for one half mile and is located at the downstream end of the watershed. By virtue of the greater volume of water passing through the third sink, it takes larger volumetric sink changes to elicit a noticeable change. The first sink is the most sensitive to variation.

4.5 Summary

The model RWQM was applied to the Aberjona to simulate the quantitative and qualitative interactions between the baseflow and stormwater runoff components of the flow in the Aberjona River. Phosphorus and total coliforms were simulated in detail using the model. Suspended solids, nitrogen, and BOD were simulated using STORM, and heavy metals loads were estimated from observed concentrations at the gauge. Table 4.12 is a summary of all average annual constituent loadings to Upper Mystic Lake. Table 4.13 is a summary of metals loadings.

The following chapter relates these loadings to lake water quality and to potential water uses. Water quality controls are also presented in reference to their potential for reducing the loads to acceptable levels.

TABLE 4.11

SENSITIVITY ANALYSES FOR RWQM VOLUMETRIC SINKS

Volumetric Sinks (mg/l/day)			Average Phosphorus Concentrations (mg/l)		
Sink No. 1	Sink No. 2	Sink No. 3	Mill St.	Washington Street	USGS Gauge
0.0	0.0	0.0	0.11	0.12	0.13
0.05	0.025	0.05	0.05	0.06	0.06
0.02	0.005	0.07	0.06	0.09	0.09
0.01	0.01	0.01	0.11	0.09	0.09
0.02	0.005	0.20	0.06	0.09	0.05

TABLE 4.12
ANNUAL LOADINGS FOR PRINCIPAL CONSTITUENTS TO UPPER HYSTIC LAKE (LB/YEAR)

Constituents	A B E R J O N A R I V E R			D I R E C T D R A I N A G E T O L A K E								Ground- water Load	Load From Bottom Sediments	Total Load To Lake
	Baseflow ¹	Urban Runoff ²	Sweetwater Supply ³	West Shore Inlet		Boat Club Inlet		DIRECT						
				Baseflow	Urban Runoff	Baseflow	Urban Runoff	Baseflow	Urban Runoff					
TSS	94,555	208,580	134,700	156,780	39,290	830	24,060	1,045	28,575	0	0	551,075		
BOD	70,915	140,955	15,915	1,185	2,315	1,040	2,495	860	1,685	*	*	237,365		
Total P	1,790	1,560	1,290	30	65	520	345	20	50	30	750	6,420		
TKR	130,330	84,460	11,865	330	620	1,310	760	240	450	2,100	*	230,365		
Nitrate	40,890	77,155	5,210	2,455	1,240	2,705	1,215	1,785	905	1,600	*	131,760		
Ammonia	138,000	75,900	1,160	865	675	60	70	615	490	0 ³	*	217,815		

¹As measured @ USGS Gauge

²Total = E (urban runoff + baseflow)

³Included in TSS load

*Not Computed

¹As measured @ USGS Gauge

²Total = Σ (urban runoff + baseflow)

³Included in TKR load

* Not Computed

Table 4.13

METALS LOADS TO UPPER MYSTIC LAKE
(LBS/YEAR)

Metal	ABERJONA RIVER			DIRECT LAKE DRAINAGE						Total Load To Lake
	Baseflow	Urban Runoff	Sewerwater Sanitary Effluent	YACHT CLUB		GOLF COURSE		DIRECT		
				Baseflow	Urban Runoff	Baseflow	Urban Runoff	Baseflow	Urban Runoff	
Aluminum	2,550	6,785	5,220	40	280	25	450	30	205	10,365
Arsenic	100	1,355	20	7	3	4	4	5	3	1,500
Cadmium	0	0	0	0	0	0	0	0	0	0
Chromium	0	0	0	0	0	0	0	0	0	0
Copper	0	1,355	870	5	20	5	40	4	15	2,315
Iron	17,890	20,350	8,700	160	315	40	370	105	230	39,440
Lead	0	600	350	0	40	3	20	0	30	1,125
Manganese	5,110	20,350	870	30	30	2	55	20	20	25,615
Nickel	510	0	90	5	3	0	5	4	3	530
Tin	0	0	20	210	140	50	35	155	100	690
Zinc	1,020	1,355	870	20	35	2	15	15	25	2,485

Total = E (baseflow and urban runoff columns) rounded to nearest 5 lbs.

CHAPTER 5

SIMULATION OF CONTROL ALTERNATIVES

5.1 Introduction

In previous Chapters the characteristics of and water quality problems associated with urban runoff in the Upper Mystic Lake watershed were described. The sources of coliform bacteria, plant nutrients, and other constituents of concern include the cross-connected sewer network in the Sweetwater Brook basin, leachate from waste disposal sites in the upstream reaches of the Aberjona, and urban runoff. To prevent excessive coliform levels in the lake and to decrease the eutrophication potential, both of which limit the lake's recreational potential, remedial action may be necessary.

This Chapter presents an assessment of the need for control strategies, and describes available control strategies, for reducing the detrimental effects urban stormwater has on the receiving waters. Vollenweider plots are used to define the eutrophication potential of the lake under existing and various controlled conditions. A set of potential controls is established and analyzed for feasibility, effectiveness, and acceptability.

5.2 Effects of Implementing Control Strategies on Water Quality

5.2.1 Phosphorus

The total phosphorus loading to Upper Mystic Lake comes from three principal sources:

1. Aberjona River
2. Direct lake drainage
3. Lake sediments

The Aberjona River contributes about 4,640 pounds of phosphorus to the lake annually. Of this, about forty percent comes from baseflow which is half of the total flow, and the remainder from urban runoff. The second source of phosphorus is the 1,515 acres that surround and drain directly into the lake, called Direct Drainage, West Shore inlet, and Boat Club inlet in this study. Included in this source is a significant portion of downtown Winchester. The annual loading from this area is approximately 1,030 pounds. Of that total,

460 pounds is contributed by urban runoff and the rest from baseflow. Finally, when the hypolimnion of Upper Mystic Lake turns anaerobic during the summer months, phosphorus contained in the sediments is released. Total phosphorus loads from this source have been estimated by DEQE as 750 pounds per year. Groundwater flow to the lake accounts for another 30 pounds, a negligible amount when compared to the other sources.

A number of researchers have developed graphical input/output models for the analysis of the eutrophication of freshwater, phosphorus-limited lakes. These models predict the trophic status as a function of phosphorus loading and lake physical characteristics such as depth, flushing rate, and surface area. Vollenweider (1968) initiated such model development, and expanded upon his original work in 1975 and 1976. His 1975 model has proven to be generally applicable to lakes in the Northern temperate zone, and is easy to apply as a tool that indicates whether or not a problem may exist.

Lake quality analyses in this report are limited to the application of the Vollenweider (1975) input/output model. The trophic status of the lake as a result of varying levels of phosphorus loading are analyzed. The different phosphorus loadings are then correlated with the controls necessary to reach such loadings later in this chapter. The ordinate on the Vollenweider plot is the product of the mean lake depth (z) and the flushing rate (ρ), where the flushing rate is the average annual inflow divided by the lake volume. The mixing of phosphorus loads and lake water is a complex process; the Vollenweider model was applied to the main body of the lake and to the entire lake to analyze the characteristics of each. Since the two forebays are physically unlike the main basin, it is likely that they react independently to the phosphorus loading. Table 5.1 displays the conversion of annual phosphorus load from pounds/year to the units required in the Vollenweider analysis, grams per square meter per year. It should be kept in mind that Vollenweider's plots are only useful as general indicators of the eutrophic potential of lakes and should not be misconstrued as exact representations of lake trophic status.

Figures 5.1 and 5.2 are Vollenweider plots using different lake volumes. Figure 5.1 considers the main basin volume only, while Figure 5.2 is for the entire lake. In each plot, the phosphorus loading clearly places the total load in the eutrophic (excessive loading) zone. Each plot also displays what reduction levels are required to achieve mesotrophic and oligotrophic loadings. For example, from Figure 5.2, the phosphorus load would have to be reduced by 77 percent after elimination of the sediment and Sweetwater sewage sources to bring it within the mesotrophic range, and 90 percent to the oligotrophic range.

Given that the annual phosphorus loading is of sufficient magnitude to promote plant productivity and massive algae blooms, the next step is to determine what measures can be taken to reduce the phosphorus loads to acceptable levels. About forty percent of the phosphorus load from the Aberjona River is in solution with the remainder in particulate form. Basinwide, the dissolved fraction is

TABLE 5.1

CONVERSION TABLE FOR ANNUAL PHOSPHORUS LOADINGS

<u>Source</u>	<u>(lb/yr.)</u>	<u>Main Basin Only (g/m²/year*)</u>	<u>Main Basin and Forebays (g/m²/yr**)</u>
<u>Aberjona River</u>			
Urban Runoff***	2,850	2.53	1.92
Baseflow	1,790	1.59	1.21
<u>Direct Lake Drainage</u>			
Urban Runoff	460	0.41	0.31
Baseflow	570	0.51	0.38
<u>Groundwater</u>	30	0.03	0.02
<u>Lake Bottom Sediments</u>	<u>750</u>	<u>0.67</u>	<u>0.50</u>
TOTAL:	6,450 lb/yr	5.74 g/m ² /yr	4.34 g/m ² /yr

* Based on surface area of 126 acres.

** Based on surface area of 166 acres.

*** CSO contribution equals 1720 pounds.

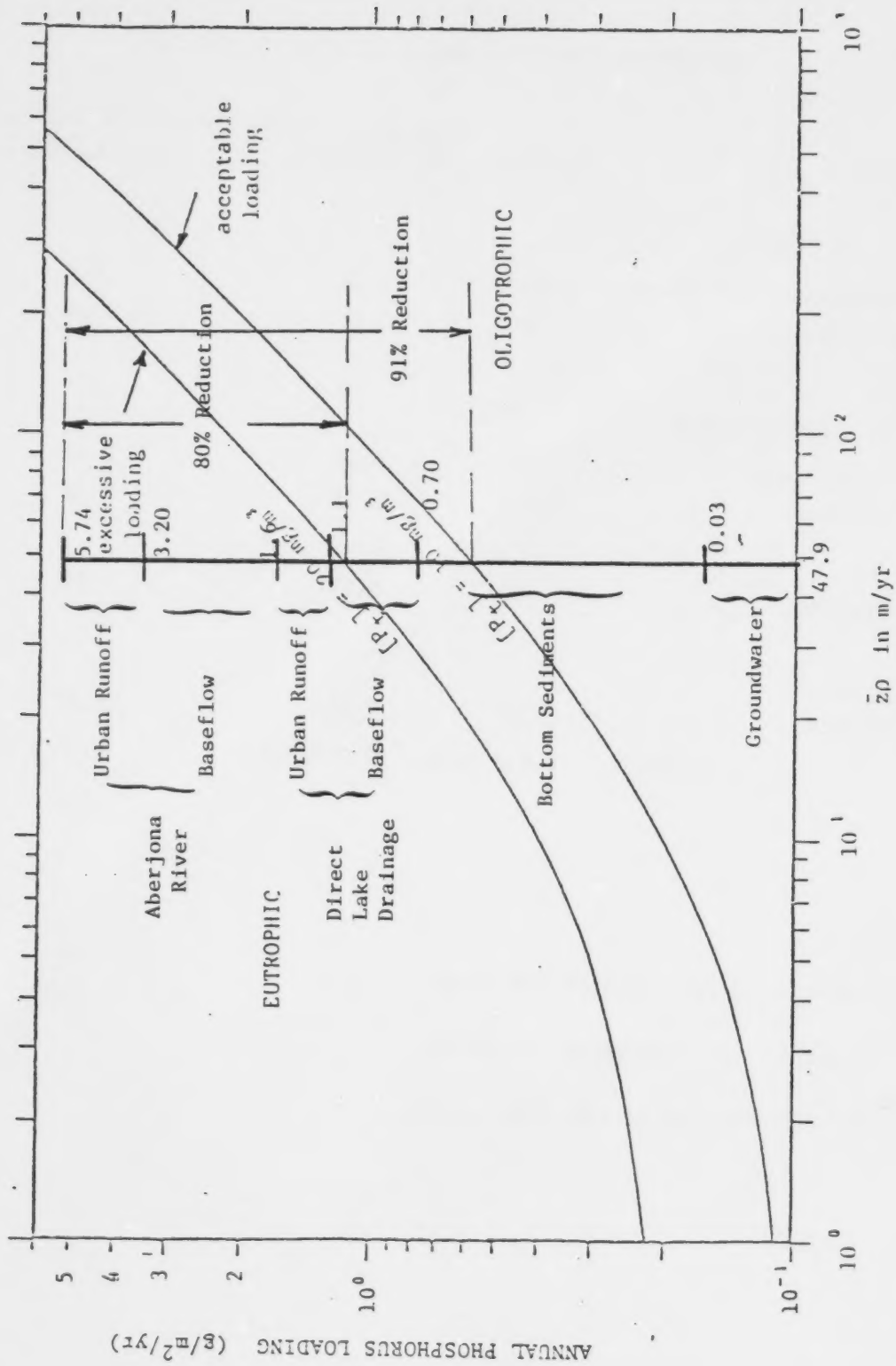


Figure 5.1

Nutrient Loading/Upper Mystic Lake Trophic Status - Main Basin Only
(Based on Vollenweider (1975))

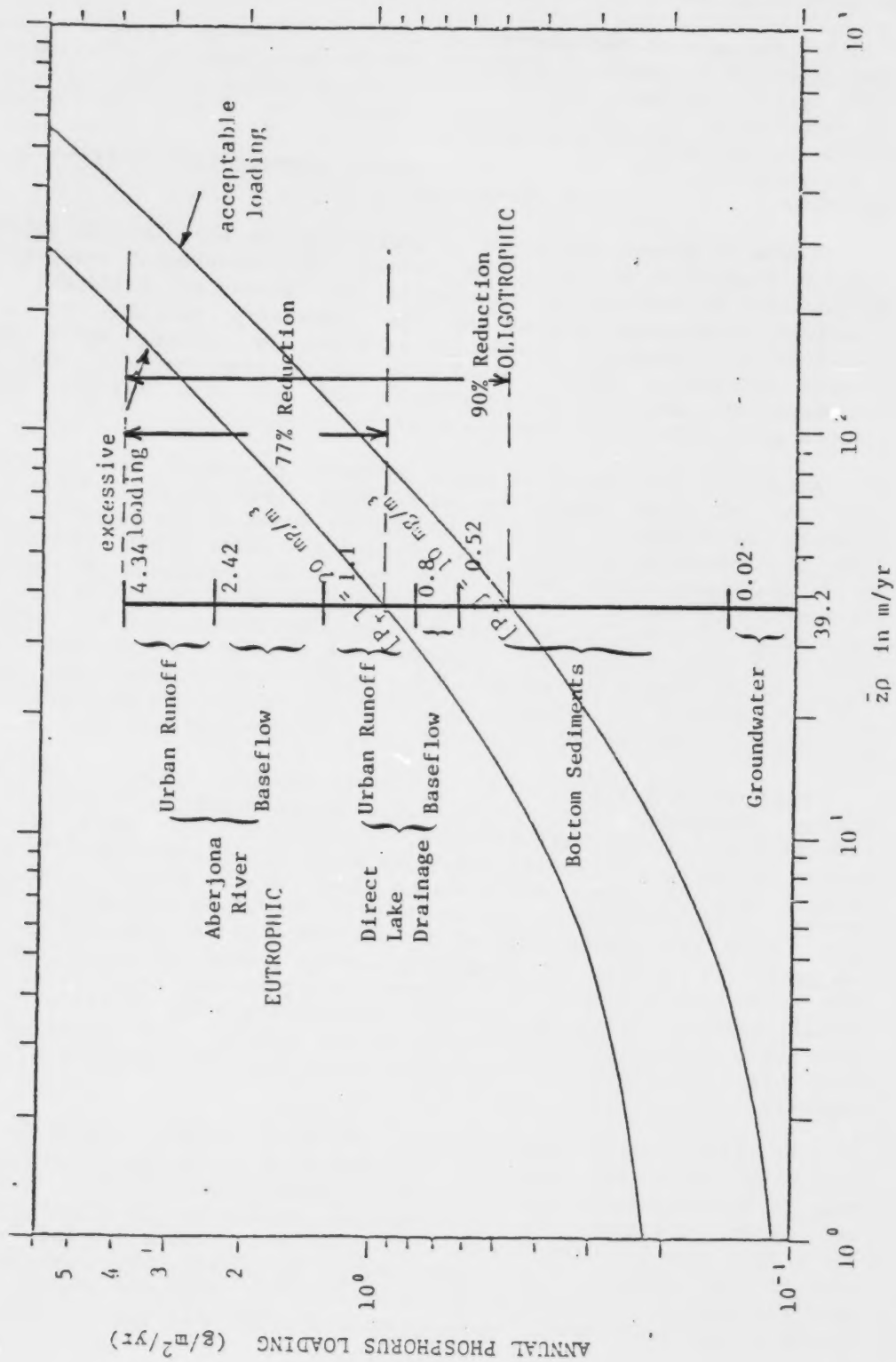


Figure 5.2
Nutrient Loading/Upper Mystic Lake Trophic Status - Main Basin and Two Forebays

about 50 percent of the total load. The load contributed by direct drainage to the lake is also about 50 percent dissolved. Phosphorus released from the bottom sediments is 100 percent dissolved.

Phosphorus that has adsorbed to soil particles and settled to the lake bottom will remain so providing anoxic conditions do not develop. Upper Mystic Lake has a very high iron content which serves to bind the phosphorus to the sediment. Should the hypolimnion become anaerobic, the phosphorus-binding form of iron (Fe^{+++}) is transformed to a non-binding form (Fe^{++}); as a result, phosphate is released from the sediments as dissolved phosphorus.

Plants in general and algae in particular use only the dissolved form of phosphorus in the growth process; thus management strategies should focus on controlling the sources and means of transport of dissolved phosphorus because of its importance relative to lake productivity. However, there is considerable cycling among the various phosphorus forms in solution, which means that all forms of phosphorus are important to consider. The following section will discuss applicable control strategies.

Action can and should be taken, however, to reduce the existing load and at least decelerate the eutrophication process. Table 5.2 presents the results of reducing phosphorus loads in the watershed by fifty and ninety percent and of separating the sewer cross-connections in the Sweetwater Brook basin. At the gauge, maximum phosphorus concentrations would be reduced from 0.24 mg/l to 0.19 mg/l by separating the CSOs. At Washington Street, maximums would be reduced from 0.58 mg/l to 0.42 mg/l. Average concentrations at the gauge for the six month simulation period do not change significantly even with the CSO problem corrected. This fact underscores the importance of the baseflow contribution to average phosphorus concentration.

With the CSOs separated and a ninety percent reduction of wet weather phosphate loads regionally, maximum concentrations would be reduced from 0.24 mg/l for existing conditions to 0.07 mg/l at the gauge. At Washington Street, maximums would be reduced from 0.58 mg/l to 0.13 mg/l. Maximums at Mishawum Road would remain unchanged. Average concentrations at the gauge would drop from 0.07 mg/l to 0.05 mg/l. Thus, the predominance of dry-weather flow is evidenced by the insignificant change in long-term average phosphorus concentrations with urban runoff cleaned up. However, a significant fraction of the annual loading would be removed. Controlling urban runoff will not stop algal productivity in the lake as the loading from baseflow is also high and capable of supporting algae, but the situation will be improved.

To gain better understanding of what effect cleaning up Sweetwater CSOs and removing 90 percent of wet weather loads would have on eutrophication potential, the impacts of each control measure are shown on Figure 5.3. With the CSOs corrected, the existing load would drop from 4.34 g/m²/yr to 3.81 g/m²/yr. Superimposing a 90 percent wet-weather load reduction on top of the CSO cleanup would drop the load to 2.3 g/m²/yr, still within the eutrophic range, but closer to the mesotrophic region. It is obvious that urban stormwater

TABLE 5.2

MEAN AND MAXIMUM PHOSPHORUS CONCENTRATIONS IN THE
 ABERJONA RIVER FOR DIFFERENT REMOVAL RATES

Description of Simulation	Period of Simu- lation	Mean/ Maximum	Phosphorus Concentrations (mg/l)		
			Mishawum Road	Washington Street	USGS Gauge
Existing Conditions - Dry Weather Flow	5 days	Mean	0.09	0.13	0.07
Existing Conditions - Wet and Dry Weather Flow	6 mos.	Mean	0.09	0.16	0.07
		Max.	0.09	0.58	0.24
Revised Conditions: a) Separate Sweetwater CSOs	6 mos.	Mean	0.09	0.13	0.07
		Max.	0.09	0.42	0.19
Revised Conditions: a) Separate Sweetwater CSOs, and b) Reduce Phosphorus Loads by 50% regionally	6 mos.	Mean	0.09	0.13	0.05
		Max.	0.09	0.23	0.10
Revised Conditions: a) Separate Sweetwater CSOs, and b) Reduce Phosphorus Loads by 90% regionally	6 mos.	Mean	0.08	0.10	0.05
		Max.	0.09	0.13	0.07

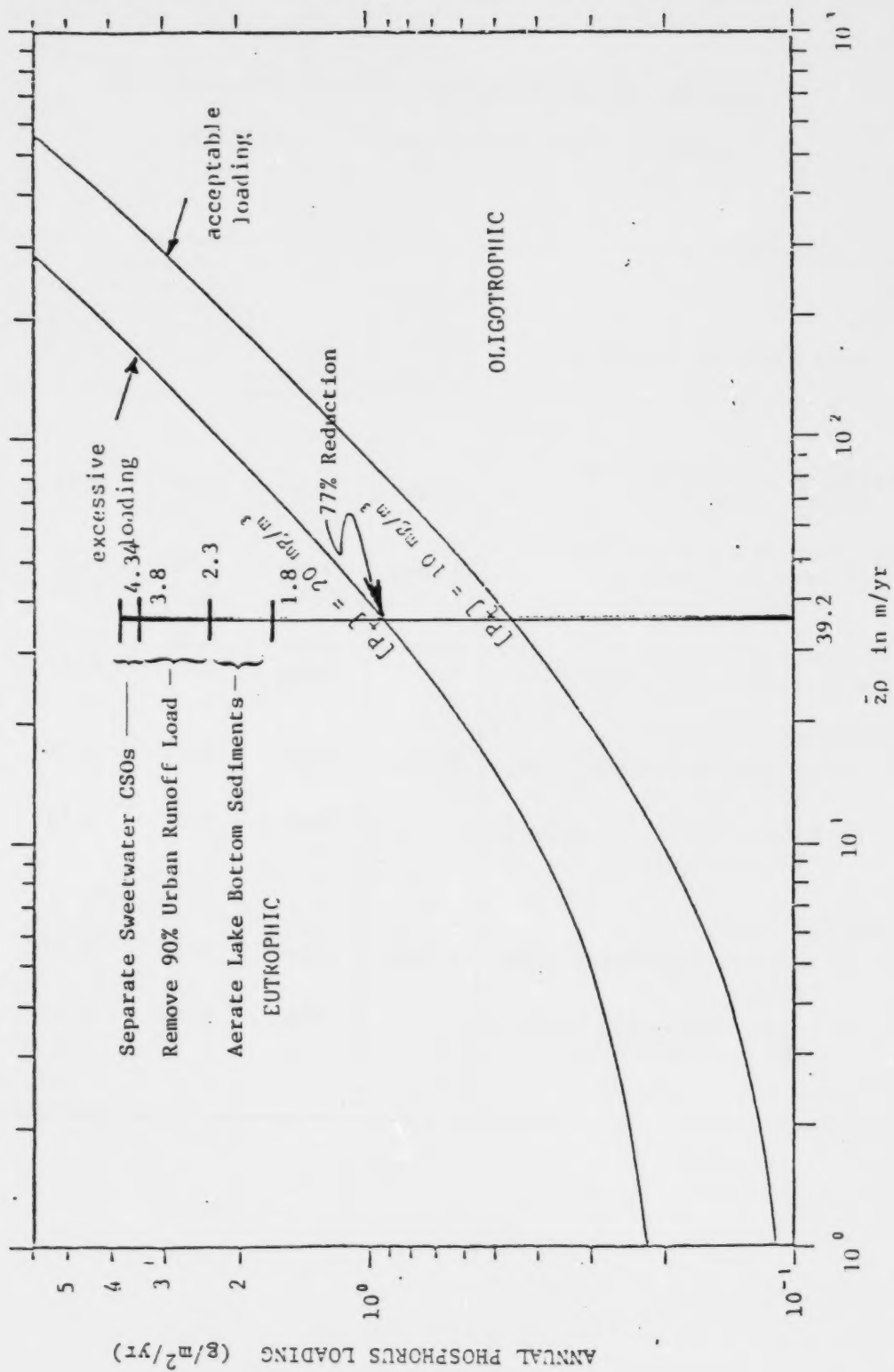


Figure 5.3

Upper Mystic Lake Trophic Status With Different Control Strategies

controls alone will not solve the potential eutrophication problem in the lake.

Figure 5.2 shows that a 77 percent reduction in phosphate load is necessary to bring the annual loading to the mesotrophic level. Aerating the lake would effectively prevent the phosphorus in the sediments from being released by keeping the hypolimnion aerobic. Because the sediments contribute 11 percent of the load, aeration would reduce the annual load by the same amount. Other potential control measures are discussed in Section 5.3.

5.2.2 Coliform

Coliform bacteria are used as indicators of fecal contamination. The wet weather fecal coliform data collected during the field program were not sufficient for use in modeling or load computation, and as a result the total counts had to be used to predict the coliform loading from urban runoff. The use of total coliforms in the simulation and comparison to total coliform standards should not adversely affect the results of the analysis.

Wet weather total coliform levels were measured at the instream and end-of-pipe stations from grab samples taken during the sampling program. Dry weather levels were taken from Water Quality Surveys conducted by the MDC and more recent field surveys by DEQE. Coliform was not simulated with STORM as the data base was not sufficient to characterize the accumulation/washoff process. The field values were used to determine representative concentrations of coliform for the various subbasins.

Representative values were assigned to wet weather and dry weather flows in all of the subbasins. The wet weather values assigned to Sweetwater Brook were considerably higher than the other subbasins due to the sewage overflows. There are also dry weather sewage overflows to Sweetwater, but these are not well quantified, and the most representative value considering all data was assigned for dry weather quality. These values were input to RWQM for the Aberjona River simulation. Dry and wet weather average coliform concentrations were assigned in the following manner:

- o Dry-weather flow - Sweetwater Brook: 2000 MPN/100ml
- o Wet-weather flow - Sweetwater Brook: 3,000,000 MPN/100 ml
- o Dry-weather flow - Remaining Subbasins: 2000 MPN/100 ml
- o Wet-weather flow - Remaining Subbasins: 10,000 MPN/100 ml

It is recognized that coliform levels show great variation during the course of a storm and from storm to storm. The RWQM simulations were an attempt to assess "typical" coliform loadings over the course of a year and the maximum levels that could be expected. Existing data show that while coliform violations at the gauge are a frequent occurrence in both wet and dry weather, no coliform violations have been recorded at Sandy Beach. While average coliform levels do not pose a threat to the beach, the "shock" or maximum levels are of concern since it is these short-duration high-intensity levels which could force beach closure.

The greatest coliform sources in the watershed are CSOs. The Sweetwater basin cross-connections are the major source of coliform, but others exist near Horn Pond Brook Road, the Winchester Boat Club, and Route 3 in Winchester. The ducks in Winchester Center can also be a significant source, as many as 18 billion coliform organisms/duck/day.

Separating the Sweetwater CSOs would markedly improve water quality in the Aberjona River. Based on 6-month RWQM simulations, (geometric) average coliform levels would be reduced from 3,100 MPN/100 ml to 1,050 MPN/100 ml at the gauge. More importantly, maximum concentrations would be reduced from 480,000 MPN/100 ml to 7,800 MPN/100 ml. The analysis was based on no change in dry-weather concentrations but with wet-weather levels reduced from 3,000,000 MPN/100 ml to 10,000 MPN/100 ml in the Sweetwater subbasin.

Separating Sweetwater CSOs takes on even greater significance when coliform levels in Upper Mystic Lake are considered. Estimates were made on the effect changing water quality conditions in the Aberjona River would have on water quality at Sandy Beach. River inflows pass through the two forebays before reaching the main body of the lake. The first forebay has a volume of 119 acre-feet and is about 6 feet deep; the second is 87 acre-feet in volume and 8 feet deep. Both forebays act as detention ponds, offering quiescent conditions, dilution capabilities and ample opportunity for coliform dieoff. By considering both forebays as completely mixed tanks, where inflow equals outflow, retention times can be computed. The length of time it takes water to move from the inlet through the two forebays and into the main lake body is dependent on Aberjona flow conditions. Retention times have been computed for different Aberjona River flows by DEQE, and are presented in Table 5.3.

Dilution rate is an expression of the number of volume changes occurring in the forebays per unit of time. Dilution rate is the reciprocal of retention time. Table 5.4 shows corresponding dilution rates for different Aberjona flow conditions. From these values it is apparent that dilution alone will result in an order of magnitude decrease in coliform concentrations.

Although dilution serves to reduce the concentration of coliform organisms, the tributary near the Boat Club is introducing high concentrations of coliform into the second forebay. The average annual discharge of the tributary is 0.8 cfs. Coliform levels measured from grab samples collected by DEQE ranged from 7,000 to

TABLE 5.3

RETENTION TIMES IN FOREBAYS

Flow Conditions	USGS Gauge Flow (cfs)	Retention Time (days)
Dry	<5	19
Average	15	8
Wet	>50	2

TABLE 5.4

DILUTION RATES IN FOREBAYS

Flow Conditions	USGS Gauge Flow (cfs)	Dilution Rate (1/day)
Dry	<5	1/19
Average	15	1/8
Wet	>50	1/2

409,000 MPN/100 ml. Wet-weather concentrations (geometrically) average 17,000 MPN/100 ml. Overall, the Boat Club tributary contributes 6 percent of the average annual coliform load to the lake.

An analysis was conducted to determine what effects different control strategies would have on coliform levels at Sandy Beach. First order dieoff rates were applied to geometric averages and maximum concentrations simulated at the gauge using the equation:

$$C_t = C_0 \exp (-kt) \quad (5.1)$$

where: C_t = coliform concentration at time t

C_0 = initial coliform concentration

k = dieoff rate

t = time

Geometric averages for the Boat Club tributary were also included in the analysis. Table 5.5 presents the results of cleaning up Sweetwater Brook CSOs and applying various coliform removal rates to wet weather loads. A first order dieoff rate of 1.1/day was used in the analysis; this value was obtained in the calibration of RWQM (Section 4.4.7) and is appropriate for application here.

The most important point is that separating the Sweetwater CSOs would result in the Aberjona contributing virtually no coliform at Sandy Beach. Coliform violations at the USGS gauge would still occur, but the two forebays provide enough of a buffer that coliforms discharged from the Aberjona River would not cause water quality standard violations at Sandy Beach. This is not to say that the Aberjona does cause violations, but the potential exists in combination with the Boat Club Inlet discharge to cause high coliform concentrations at the Beach.

Removing fifty percent of the coliform loads in the remainder of the watershed without cleaning up Sweetwater CSOs would not solve the problem, as maximum coliform levels could potentially be in violation of Class B standards at the beach. Thus, the solution seems clear, and separation of the Sweetwater CSOs is already in the planning stages.

Figures 5.4 and 5.5 are influence curves relating maximum coliform counts at Sweetwater Brook and the gauge, and at the gauge, and Sandy Beach, respectively.

5.3 Control Measures

Nonstructural and structural control measures offer considerable promise as the first line of action to control urban runoff pollution. By treating the problem at its source or by curtailing its opportunity to develop, multiple benefits can be realized. Structural control

TABLE 5.5

EFFECTS OF CONTROL STRATEGIES ON
COLIFORM LEVELS AT SANDY BEACH
DUE TO LOADS FROM ABERJONA

Description of Simulation	k(1/day)	Coliform Levels @ Gauge ¹ (MPN/100 ml)		Coliform Levels at Beach ² (MPN/100 ml)			
		Geometric Mean	Maximum	Wet Conditions (2 days)	Average Conditions (8 days)		
				Geometric Mean	Maximum	Geometric Mean	Maximum
<u>Existing Conditions:</u>	1.10	3,100	480,000	340	5,320	0.5	70
<u>Revised Conditions:</u>							
o Separate Sweetwater CSOs	1.1	1,050	7,800	115	860	0.2	1.2
o Separate Sweetwater CSOs and Reduce Total Coliform Load by 10%	1.1	1,020	7,000	110	780	0.2	1.0
o Separate Sweetwater CSOs and Reduce Total Coliform Load by 50%	1.1	900	3,900	100	430	0.1	0.6
o Separate Sweetwater CSOs and Reduce Total Coliform Load by 90%	1.1	700	3,800	80	420	0.1	0.6
o Reduce Total Coliform Load by 50% but do not separate CSOs	1.1	3,100	477,700	340	5,290	0.5	35

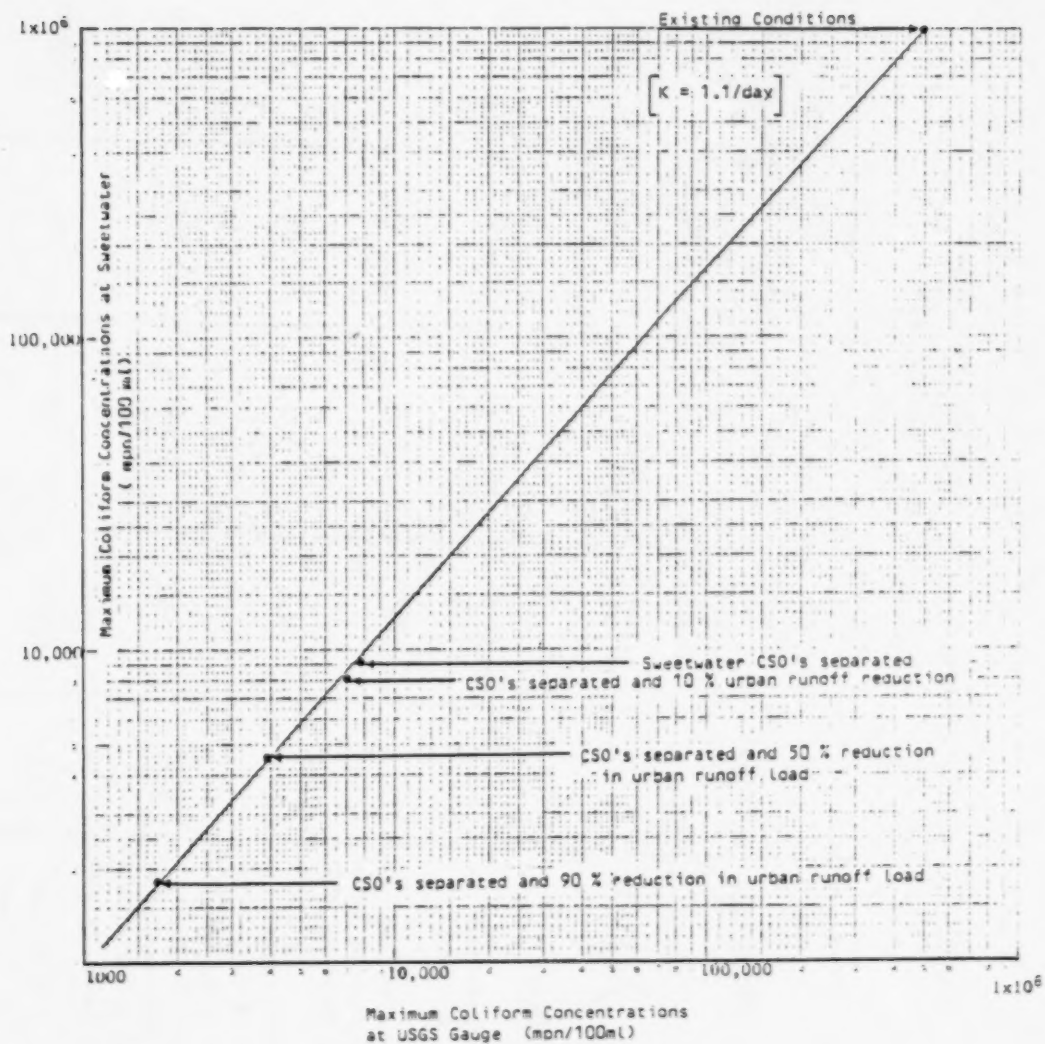
¹From 6-month RWQM Simulation

²Calculated Using $C_t = C_0 e^{-kt}$ plus dilution of one order of magnitude.

Figure 3.4

INFLUENCE CURVE

Sweetwater Coliform Levels vs Gauge Coliform Levels





measures range from constructing stormwater detention facilities to physically treating urban runoff, whereas nonstructural measures capitalize on zoning ordinances aimed at land use or erosion controls; on maintenance of existing stormwater conveyance networks, such as catch basin cleaning and street sweeping; or on maintenance of the lake as a more aesthetically pleasing environment.

5.3.1 Structural Controls

Structural measures considered in this study include:

Separating Combined Sewers: One of the greatest sources of pollution in metropolitan areas today is the existence of combined sewers and sanitary sewer cross-connections. This is true in the Mystic basin as well. To prevent overloading of some wastewater treatment plants during wet-weather periods, sewage is discharged along with stormwater to receiving waters without treatment. In other cases sanitary and storm collection systems are interconnected resulting in wastewater discharges to receiving waters. Eighteen sewer manholes in the Sweetwater Brook basin are cross-connected with stormwater lines and the resultant water quality impacts are severe. In addition, the ongoing Infiltration/Inflow Study in Winchester has identified numerous areas where sanitary sewage is discharged to the stormwater collection system. The cost of separating these lines is moderate compared with other structural measures, and the benefits in terms of water quality are pronounced. This is not an urban runoff control, but it is the most effective way of initially reducing the pollutant loadings to the lake.

Providing Additional Storage: Construction of onsite or offsite storage facilities allows urban runoff to be temporarily stored and then released at a more gradual rate. They are most often designed to prevent flooding, but offer water quality advantages as well. Longer detention times and quiescent conditions allow solids to settle out. Storage facilities include underground storage vaults, rooftops, parking lots, and detention basins. Storage basins created from natural depressions or in wetlands often require minor control structures and limited earthwork, and are up to ten times less expensive than basins that need major excavation. However, there is little available space in the watershed for the placement of detention facilities, and the capital costs of installation would be higher for ponds used for water quality control.

Physical Treatment: Physical treatment alternatives that are commonly applied to urban runoff are primarily for removal of settleable and suspended solids and floatable materials. Physical treatment facilities have demonstrated capability to handle high and variable influent concentrations and flow rates. The principal disadvantages relate to equipment idleness during dry-weather periods, the need for piping to complete the collection system, the need to discharge the removed solids, and the related costs.

Two examples of physical treatment devices are swirl concentrators and teacup solids separators. The swirl flow regulator/separator is a simple annular-shaped construction, has no moving parts, and requires minimal maintenance. It is capable of functioning efficiently over a wide range of flows, and has the ability to separate settleable organic matter and floatable solids at a small fraction of the detention time required for primary separation. Swirl concentrators operate by introducing solids at the bottom of the basin, and flow deflectors induce rotational motion. A floatables trap directs floating materials into a channel where they eventually disperse to a downshaft.

A teacup solids separator is a variation of the swirl concentrator. The teacup is vigorously stirred rotationally and then allowed to rotate freely. Solids begin to settle out as fluid rotation decelerates. The solids move progressively towards the bottom center.

Chemical Addition and Biological Treatment: Chemical and biological treatment to enhance the removal properties of the pollutants in urban runoff can be effective and have a tolerance for higher hydraulic loading rates. Unfortunately, such alternatives require a treatment facility and collection system, that is prohibitively expensive to construct and operate.

Porous Pavement: Instead of storing runoff onsite in parking areas, porous pavement which allows precipitation to percolate through the porous media to the subsurface can be retrofitted or used in new construction of parking lots and other paved areas. The rainfall passes through the rock strata, which provides a degree of natural treatment. This control strategy is most effective in large subdivisions. Because most of the Mystic basin is developed, future housing is more apt to be constructed as individual units rather than large subdivisions. Converting existing paved areas to porous materials is impractical given cost considerations. Thus, this control measure while feasible, is not practical on a wide scale given the characteristics of the watershed.

Other Structural Methods: There are other structural techniques available for limiting the impact of urban runoff on water quality. These include using gross scales and diversions, which are suitable for new construction, and should be considered in the Mystic basin. However, since the watershed is already heavily urbanized, implementing such controls will not have a significant impact on the receiving water quality.

5.3.2 Nonstructural Alternatives

Nonstructural control strategies rely on institutional arrangements such as zoning ordinances or preventive maintenance to control the sources of urban stormwater pollution. Among the nonstructural alternatives possible for the Mystic Basin are:

Zoning Ordinances: This measure depends on legislative action to effectuate desired land use or erosion control policies. Ordinances can be promulgated to require private developers to pond rainfall or rooftops and in locations of all new construction, or provide stormwater detention and grassed swales before granting sewer connection permits. Soil stabilization methods can be required to reduce erosion and porous pavement can be required in all new developments. Drainage taxes can be levied on the basis of surface area and runoff coefficient. Efforts to retain runoff onsite could be rewarded by lower charges.

Street Sweeping: Modification to or the development of a street cleaning program is a source control for the removal of 10 - 20 % of solids and related material. The effectiveness of any streetcleaning program depends on street surface conditions, accumulation rates, the cleaning program itself (i.e., frequency of cleanings and number of passes), and the type of cleaning equipment used. However, since all of the local towns have street sweeping programs, even in their post Proposition 2-1/2 status, it is prudent to use the program to efficiently remove as much of the pollutant load as possible, by sweeping as much of the area as possible, rather than sweeping exclusively in commercial areas.

Catch Basin Cleaning: In the course of a year, solids and other materials accumulate in catch basins. periodic cleaning is necessary to prevent these materials from being scoured out during intense rainstorms and released to receiving waters. Like street sweeping, catch basin cleaning will not remove large proportions of pollutants, but since the basins are cleaned periodically for aesthetic purposes and to relieve flooding conditions, it is wise to use the program to remove as much of the pollutant load as possible by developing a schedule for cleaning the basins before they fill with solids that can be flushed out during subsequent storms.

Public Education: Disseminating information concerning what individual citizens can do to help mitigate the effects of urban stormwater in their community is another effective means of controlling the problem. Public awareness of the relationship between fertilizer application and nitrogen and phosphorus runoff is but one area where public education can be effective. Lawns and gardens can flourish with reduced application rates in most areas. Anti-litter campaigns and promotion of public transportation are further areas of concentration. Stressing the importance each citizen's role plays in the cleanup of the whole watershed is imperative. It is analogous to the situation where a developer wishes to pave over a plot of land. While the incremental loss in ground perviousness will not cause a large increase in peak runoff flows, it will cause some increase and if transforming pervious areas to impervious were to take place basinwide, the results would be significant. Similarly, while one individual's attempt to take corrective action by itself will have little effect, a concerted effort on the part of a community or several communities can have a significant effect on reducing the pollution from urban stormwater.

Deicing Management: Management of highway deicing practices and salt

storage sites are particularly relevant to stormwater runoff control practices. Typical deicing practices contribute considerable chloride loads represented by increases of 40-50% during the winter months, while sanding adds considerable loads of suspended solids. The additional suspended solids cause problems in catch basins and storm and combined sewers, and require treatment later. Chemical additives to the deicing materials include cyanide, phosphate, and chromium which result in polluted snowmelt and contamination of receiving waters. In addition, these additives, which act as anticaking agents and corrosion inhibitors, may have severe latent toxic properties. Sodium ferrocyanide, for example, minimizes the caking of salt but is soluble in water and will release cyanide in the presence of sunlight.

DEQE has developed a "Road Salts and Water Supplies Best Management Practices" handbook, which details a number of measures that can be used to limit the impacts of deicing compounds on water quality. Dissemination of this document in the watershed can result in reduced pollutant loads to the receiving waters.

The amount of pollutant effectively removed by each of the structural and nonstructural controls varies considerably. Table 5.6 presents removal rates for different alternatives. In general, structural alternatives remove more of a pollutant than nonstructural alternatives. For example, a Teacup Solids Classifier can remove from forty to ninety percent of suspended solids, while erosion controls can only remove from twenty-five to fifty percent. The increased effectiveness associated with structural measures, however, comes at a high cost.

The greatest difficulty faced by any of the structural or nonstructural control strategies is that the cause/effect relationship is difficult to quantify. It is clear that onsite storage, for example, can be closely related to reduced hydrographs downstream, but the net water quality benefits are far less defined. Similarly, cleaner streets and neighborhoods and enforced anti-litter legislation will eradicate some pollutants, but the effects have not been defined for all watersheds.

5.3.3 In-Lake Control Alternatives

The structural and nonstructural alternatives discussed above all focus on removal of pollutants at the source. In many areas it is impractical or very costly to install these controls, and the nutrients must be allowed to enter a lake system. Controls do exist to deal with such situations; they are known as in-lake controls, and their purpose is to remove the nutrients after they have been utilized to promote plant growth or after they have settled out of the water column. The following are examples of in-lake alternatives applicable to the Mystic basin.

Plant Harvesting: Excessive nutrient loads are often manifested in the proliferation of rooted plants. One method for controlling the

TABLE 5.6
REMOVAL EFFICIENCIES FOR CONTROLS

Constituent (% Removal)	BOD	COD	Nutri- ents	TKN	TP	PO ₄	TS	SS	Settle. Solids	Float. Solids	Cu	Pb	Zn	Reference
<u>Control</u>														
<u>Catch Basin Cleaning:</u>														
	43						56 ≤10							Virginia State Water Control (RI, 1979) U.S. EPA, 1982 draft
<u>Detention Basin:</u>														
<u>Wetlands</u>	0-25		0-25		78			0-25 94						U.S. EPA, 1977a U.S. EPA, 1977b
<u>Erosion Controls:</u>														
<u>Sedimentation:</u>	0-25		0-25					25-50						U.S. EPA, 1977a
<u>with flocculation</u>	25-40							25-50						MAPC, 1977
<u>without chemicals</u>	60-80							70-90						MAPC, 1977
<u>chemically assisted</u>	30 68	34 45		38	20			20-60 68	90-95					U.S. EPA, 1978 U.S. EPA, 1978
<u>Street Sweeping:</u>		≤10	≤10	≤10	≤10	≤10	≤20 ≤40				≤10 ≤50	≤35 ≤50	≤10 ≤50	U.S. EPA, 1982 draft U.S. EPA, 1979
<u>Self Concentrator:</u>	25-60													U.S. EPA, 1978
<u>with screening</u>	0-25							40-60 0-25	50-90					MAPC, 1977
<u>Teacup Solids Classifier:</u>	20-40							40-90	50-100	50-100				Eutek Systems, 1978

effects of the nutrient loads is to harvest the plants. Disposal of the plants outside of the watershed is recommended, as the nutrients tied up in the plants will be removed and the impact of the nutrient discharges would be relieved. However, this is not a permanent solution, and harvesting would have to be repeated periodically.

Algae Removal: Mechanical equipment also exists for the removal of floating plants and algae. This control is also a temporary solution, but is capable of permanently removing nutrients from the watershed, if the plants are disposed of properly.

Aeration: Lake sediments can be a significant source of phosphorus when the hypolimnetic water is anaerobic. Lake aeration has been used in many locations to relieve that situation. Two types of aeration are commonly used: complete lake mixing and hypolimnetic aeration. If the lake is completely mixed, it is constantly turning over and circulating, which induces oxygen addition from the atmosphere. Hypolimnetic aeration adds air to hypolimnetic water only. The complete mixing raises the temperature of the hypolimnion during the summer, eliminating the potential for a cold water fishery. With hypolimnetic aeration, the potential exists for nitrogen accumulation to toxic levels. Both methods can eliminate the hypolimnetic phosphorus source that occurs when the hypolimnion is anoxic. Therefore, there are dual objectives: reducing the phosphorus sources and increasing the oxygen concentration to accommodate fish habitats. The potential negative impacts of the lake mixing are an increase in the detention time during the growing season, which enhances the plant growth potential; and incomplete mixing could result in nitrogen gas buildup in the hypolimnion, which could be toxic to certain fish species. Lake aeration is a relatively inexpensive and maintenance-free means of reducing the phosphorus load, while maintaining aerobic conditions.

Dredging: Dredging is one method for removing rooted aquatic plants and phosphorus in the sediments. This method is feasible because the rooted plants use the sediments, and not the water column, as a nutrient source. Dredging poses a significant disadvantage, as the dredge spoils may be classified as a hazardous waste due to the high heavy metals concentration, and disposal would be a difficult problem. Dredging is also a very expensive control to implement. When used for plant control, the plant roots should be removed to prevent immediate regrowth.

Public Participation: None of the in-lake alternatives discussed are permanent solutions for plant growth problems. Rooted plants are a particularly difficult problem as the nutrient reduction techniques do not tend to control them, as the sediment is their primary nutrient source. However, removal of the plants, including the roots, is an effective control. One method of approaching the problem is individual removal, which can be performed by homeowners. A program to inform the public of the effectiveness of this control would most likely result in encouraging some individuals to participate in a plant removal program. Individuals could also install screens or other sediment barriers that would prevent rooted plant growth. This technique has already been successfully tested on Upper Mystic Lake.

Chemical Addition: A popular means of eliminating algal proliferation problems over the past couple of decades has been chemical addition. These chemicals (herbicides or algicides), which are primarily heavy metal (aluminum, iron, or copper) salts, kill the floating plants, which in turn decay and sink to the lake bottom. While this method relieves the obstacle to having an aesthetically pleasing recreational facility, it also causes problems. The nutrients removed from the surface water by killing the plants are moved to the sediments, where they can become a future phosphorus source. The heavy metals in the chemical additive tend to build up in the sediments, and may become toxic to benthic animals and fish. In addition, chemicals have become very expensive.

Sediment Treatment: Treatment of lake sediments to limit the transport of nutrients or heavy metals into the water column is a common practice. Fiber (plastics) liners, clay or sand layers, chemical addition, and fly ash addition have all been practiced successfully.

The in-lake control techniques discussed in this section are not controls over the source, and as a result, often must be repeated periodically, but can be quite an effective means of rapidly enhancing a lake's recreational potential.

5.3.4 Control Screening

Not all of the control strategies described in the previous section are implementable in the Mystic watershed. No federal funding is available for urban runoff control, which leaves the burden to be shared by individual communities and the State. Therefore, controls must be sought that are effective, but not capital intensive, and do not require a great deal of operation or maintenance. Compounding the problem is the institutional obstacle of convincing the citizens of each of the towns that these controls are necessary to preserve a regional recreational resource.

Most of the structural alternatives are capital intensive. Detention ponds are feasible and several small ones have been constructed in the past. Active detention ponds at Beacon Street, Horn Pond Brook Road, Waterfield Road, and Washington Street in Winchester are small (less than fifteen feet long), and were constructed over fifty years ago, and with proper maintenance will continue to work effectively. Today few suitable sites for locating ponds remain in the face of rapid urbanization, and retrofitting developed areas with ponds would be difficult logistically, as low points in the watershed are required, and they are often developed. Therefore, it is worthwhile to investigate the possibility of using the existing ponds and impoundments as detention ponds, but new facilities are not a promising alternative in developed areas. However, new ponds should be considered in developing areas. If the existing ponds are to be used, they would have to be periodically cleaned or dredged, as large storms can scour the deposited solids under existing conditions.

Swirl concentrators and teacup separators are feasible in the watershed, but also not practical for widespread implementation, as each pipe ending requires a unit, if no interceptors are constructed, and every unit requires a location for disposal of the separated solids, such as a sanitary sewer. An MDC sewer would have to be used, and sufficient capacity is most likely not available.

Catch basin cleaning and street sweeping are feasible alternatives in the watershed but present strains on municipal budgets imposed by proposition 2-1/2 relegate both alternatives to lower priorities on maintenance schedules. Conversations with town highway officials revealed each community in the watershed owns at least one street sweeper. Streets are swept and catch basins are cleaned on a rotating basis. Several communities also subcontract the street sweeping. Effective sweeping practices are being studied as part of the NURP, and the results should be widely disseminated to insure proper practices are employed. But officials acknowledged that future street sweeping and catch basin cleaning efforts are being curtailed due to budget limitations.

Water quality problems caused by CSOs in the Sweetwater Brook basin are well-documented. The cross-connections have been studied extensively and remedial action proposed. The project is slated to receive funding under the Construction Grants program, and work on separating the combined sewers is scheduled to begin within two years. Ongoing infiltration/inflow studies in the other local towns will identify additional cross-connections and surcharging sewers. Section 5.2 discussed the relative impact of implementing sewage overflow control on the coliform and phosphorus levels in the receiving waters. This is not an urban runoff control, but is an effective means of improving water quality in the Mystic Basin.

Public education is another feasible alternative. Information could be disseminated about a wide range of topics, including proper fertilizer application procedures. The disadvantage of this alternative is the need for community action -- that is, the alternative will only be effective if many residents work together towards a common goal, and concerted, sustained activity is difficult to achieve. The public needs to become aware of the problems and the impacts that their collective effort can have.

Zoning ordinances are feasible; however local communities must initiate legislative action that will only benefit the region as a whole and not the single town. Nevertheless, it is in the best interest of all concerned to maximize onsite storage capacity for new construction if only to reduce flood peaks. Water quality improvements will be an added advantage. Overall, only 3,900 acres remain as open space in the watershed; most of the region has been urbanized so future land use controls will not have a significant impact.

The in-lake controls are certainly feasible for Upper Mystic Lake. In most cases these controls do not remove the pollutant source, and they only provide short time frame solutions. They require a sustained effort, and proper management of an in-lake control program can result in a significant improvement in water quality conditions and the recreational potential of the lake.

Table 5.7 lists the control alternatives considered and screens them for constituent or water use goals and practicality or implementability. Those that are physically feasible as well as implementable include:

- o Separating the CSOs in the Sweetwater Brook basin and elsewhere in the watershed
- o Establishing a public education program to alert local residents to the effects and what they can do to reduce the effects of urban stormwater
- o Street sweeping
- o Catch basin cleaning
- o In-Lake controls
- o Detention ponds (with proper maintenance for existing ponds and required for new development)

Alternatives that are feasible but not practical include:

- o Swirl concentrators
- o Teacup solids settlers
- o Zoning ordinances
- o Porous pavement
- o Stormwater treatment
- o Lake dredging
- o Lake sediment treatment

TABLE 5.7

SUMMARY OF CONTROL MEASURE SCREENING

CONTROL	CONSTITUENT/WATER USE CONTROLLED	PRACTICAL/ IMPLEMENTABLE	NOTES
Sewer Separation	All ¹	Yes	Not urban runoff control, but has significant impact on water quality.
Existing Detention Basins	Solids, nutrients, BOD	Yes	Need periodic maintenance to optimize effectiveness.
New Detention Basins	Solids, nutrients	Limited	Few available sites, limited to new development.
Construction Regulations	Solids, nutrients	Limited	Limited new development anticipated
Physical Treatment Devices	All	Limited	Need interceptors and connections to sanitary sewers to implement.
Chemical Treatment	All	No	Capital intensive.
Porous Pavement	All	Limited	For new construction only, retrofitting is impractical.
Zoning Ordinances	All	Limited	Primarily for new construction.
Street Sweeping & Catch Basin Cleaning	All	Yes	Good for removal of relatively small fraction of constituents.
Public Education	All	Yes	Effective for small fraction of constituents.
Deicing Management	Nutrients	Yes	Limited effectiveness.
Plant Harvesting	Nutrients, Aesthetics, and Recreation	Yes	Short time-frame solution.
Algae Removal	Nutrients, Aesthetics, and Recreation	Yes	Short time-frame solution.
Aeration	Nutrients, DO, Fishery	Yes	Effective for nutrient source limitation.
Dredging	Nutrients, Aesthetics, and Recreation	Yes	Costly and may result in a hazardous waste disposal problem.
Herbicide/Algicide Application	Nutrients, Aesthetics, and Recreation	Yes	Short-term solution, can increase nutrients and heavy metals in the sediments.
Sediment Treatment	Nutrients	Yes	Requires chemical addition or capital intensive liner installation.

¹All includes solids, BOD, nutrients, and coliforms.

5.4 Summary

5.4.1 Phosphorus

The total annual phosphorus load to Upper Mystic Lake totals 6,450 pounds; of this 1,790 pounds come from Aberjona dry weather flow and 2,850 pounds from Aberjona urban runoff; 1,030 pounds is contributed by direct drainage to the lake (570 pounds of which is from dry weather flow), and 750 pounds are released from the bottom sediments. Given the size and flushing rate of the lake, the total phosphorus loading is excessive and places the lake clearly in the eutrophic range. In general, about half of the runoff loading is in the dissolved form. Even if all of the particulate phosphorus were to be removed from the basin, enough phosphorus would remain in dissolved form to maintain the lake's eutrophic status. Thus, the eutrophication process cannot be practically reversed in Upper Mystic Lake, but only decelerated.

The most effective means of reducing phosphorus loads would be to separate Sweetwater CSOs and to aerate the lake. The phosphorus loading would be reduced significantly, but eutrophic conditions would still prevail. Dry-weather loadings (i.e., loads contributed by baseflow) are as significant a phosphorus source as urban runoff in both the Aberjona River and direct lake drainage. Thus, cleaning up urban stormwater solves but part of the problem. Figure 5.6 is curve which shows how phosphorus load varies with baseflow concentration. Figure 5.7 is an influence curve which displays phosphorus loads from the different subbasins versus loads at the gauge.

To bring the annual loading to an acceptable level, a 77 percent reduction in phosphorus load would be required (from 4.34 g/m²/year to 1.0 g/m²/year) or 4,940 pounds/year. Separating Sweetwater CSOs would reduce the annual load by 0.54 g/m²/year (or 800 pounds/year). Aerating the bottom sediments of the lake would eliminate that phosphorus source, and reduce the total load another 0.5 g/m²/year or (750 pounds/year). Thus, another 2.3 g/m²/year or (3,400 pounds/year) would need to be removed to bring the entire load to the mesotrophic level. Weed harvesting, catch basin cleaning, street sweeping, wetlands treatment, sedimentation, and public education would be the mechanisms by which the remaining load reduction could be achieved. Since catch-basin cleaning, street sweeping, wetlands treatment, and sedimentation already occur to some extent throughout the basin, and the opportunity to increase the contributions of each is minimal given municipal budget constraints and urban development pressures, weed harvesting, algae removal, and public education are the most promising measures for further reducing phosphorus loads to the lake and maintaining the recreational water uses. Whether the latter two measures can reduce the remaining load from 4,900 pounds/year to effectively 1,500 pounds/year cannot be determined, but both would reduce the load to some extent and aid in decelerating the eutrophication process, while relieving the effects of excess phosphorus loading.

Figure 5.6
BASEFLOW PHOSPHORUS CONCENTRATION VS BASEFLOW PHOSPHORUS LOAD

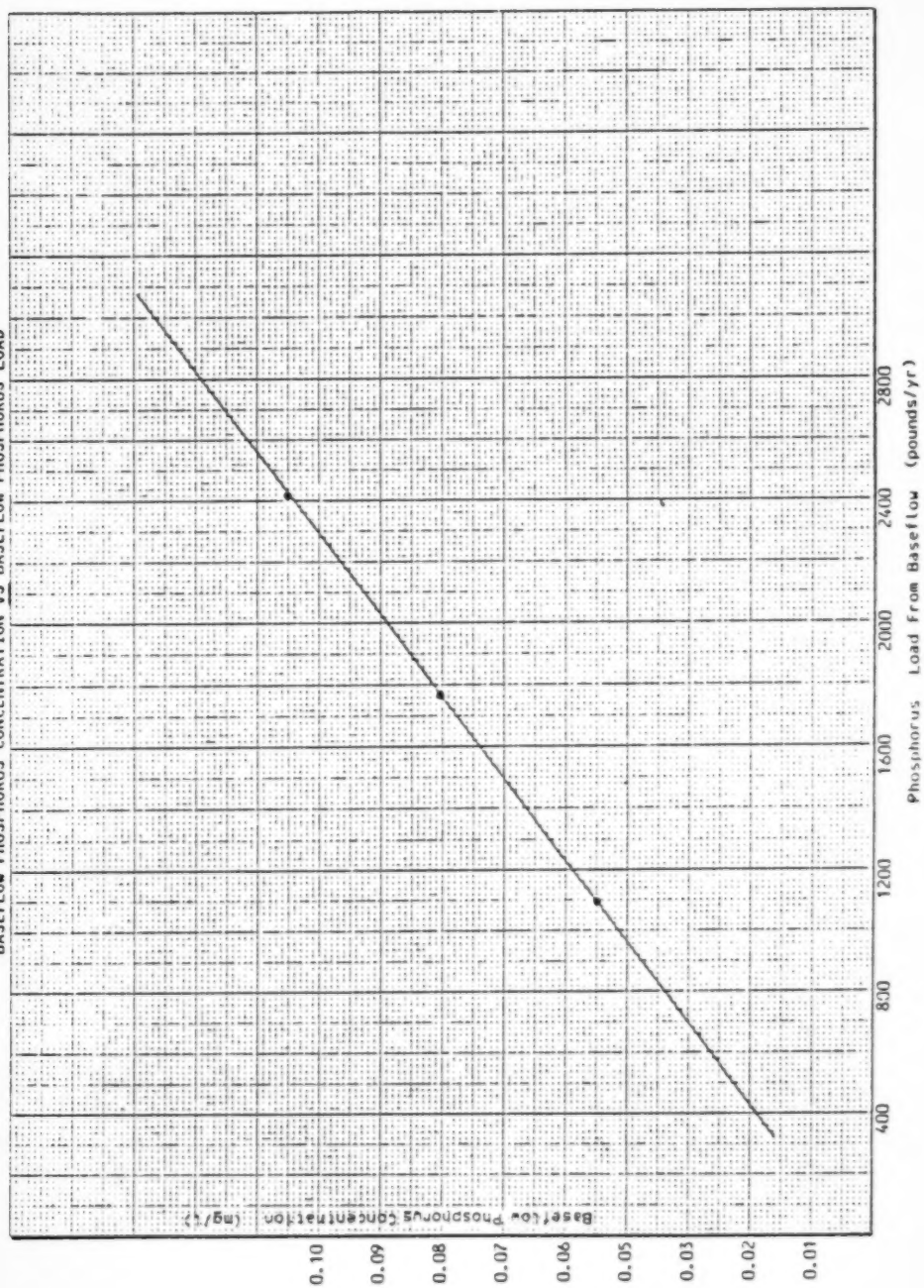
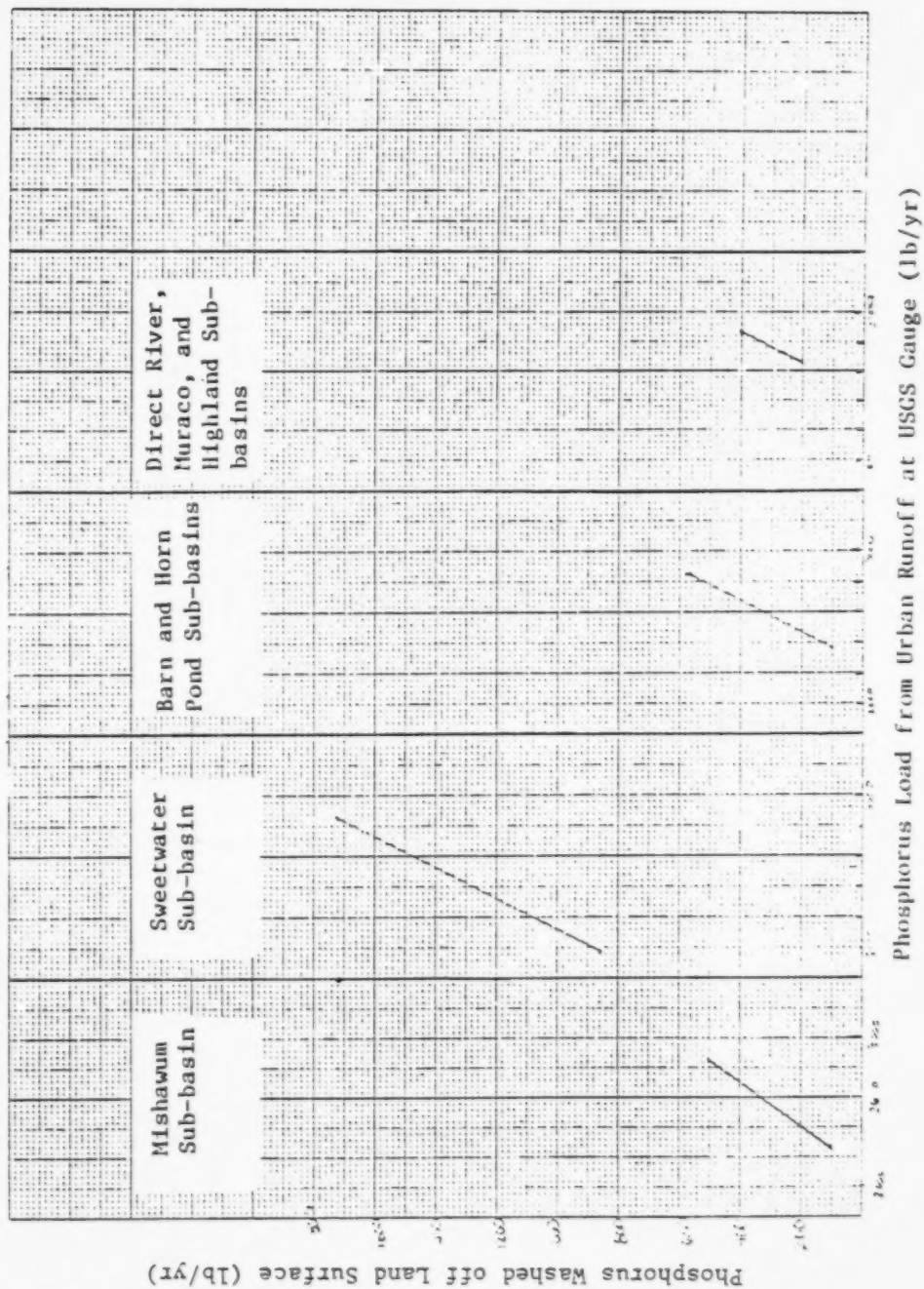


Figure 5.7

Influence Curve: Phosphorus Washed Off Land Surface vs.
Phosphorus Load at Gauge from Urban Runoff



5.4.2 Coliform

Class B water quality standards violations for coliforms currently occur in the Aberjona River, and may occur in Upper Mystic Lake as well. The conclusion reached is that separating the Sweetwater CSOs would reduce maximum coliform counts to such levels that they would not pose a threat to Sandy Beach, although standard violations would still occur in other areas. Even with the CSOs cleaned up, however, coliform levels in the Aberjona River would still be in violation of Class B water quality standards. But the detention times and dilution capabilities afforded by the two forebays allow coliform organisms introduced with the Aberjona and Boat Club tributary inflows to die off to acceptable levels. Reducing wet weather coliform levels on a regional basis by a certain percentage without separating the Sweetwater CSOs would not solve the problem and maximum coliform concentrations would still threaten the beach. In addition, this would require capital-intensive disinfection facilities. Separating the CSOs, then, offers the best solution: coliform levels would no longer threaten the beach and no other control measures would be required. Recreational opportunities in the two forebays, however, could be restricted after storms, because the water quality standard violations indicated by coliform organisms could still exist at certain times.

CHAPTER 6

SUMMARY

The purpose of this study was to assist the DEQE in the analysis of the urban runoff impacts on water quality in the Upper Mystic Lake watershed. CDM's technical responsibilities included:

1. The analysis of hydrologic and water quality data, both historic and as collected during the study;
2. The application of the STORM simulation model to characterize the rainfall/runoff and pollutant washoff processes that are taking place;
3. Simulation of the Aberjona River quality using the model RWQM;
4. Further application of the two models to predict the loadings of various constituents to Upper Mystic Lake; and
5. Identification of control alternatives and preliminary screening of those that are practical, effective, feasible, and implementable.

The data base that was analyzed included historic data collected by the MDC and MDWPC and those collected during this study by the MRWA volunteers, DEQE staff, and EDP. The MRWA data were used to characterize the dry weather and baseflow components of the Aberjona River. These data were sufficient to determine those characteristics and to show that there is not a significant difference between wet weather and dry weather quality in the Aberjona River for most of the constituents analyzed. The results of the MRWA data analysis were used directly in the simulation of the Aberjona River water quality.

The DEQE data were collected to ascertain the quality in specific locations under various hydrologic conditions. This data collection effort identified areas of high phosphorus and coliform concentration in the watershed, as well as providing additional data for characterizing the runoff quality in the area.

The EDP data were limited to the sampling of several storm events. Samples were collected throughout the storms at both instream and end-of-pipe locations. These data were used to determine the

runoff fraction of total rainfall; to characterize the urban runoff quality; to correlate the runoff quality with land use; and to develop parameter values for the simulation of the rainfall/runoff and pollutant washoff processes.

STORM was used to simulate the hydrologic and water quality aspects of the urban runoff process. Field data were used to determine characteristic parameter values that are used to predict the quantity and quality of urban runoff. Loadings of total suspended solids nitrogen, phosphorus, phosphate, and BOD were computed. Coliform organisms were not simulated using STORM, as the data base was insufficient. The results of the application of STORM were estimates of annual average runoff loads for the constituents listed above.

Observed water quality problems in the watershed include high coliform concentrations in the Aberjona River; plant growth, both rooted and floating, in the lake; and an anaerobic hypolimnion. The anaerobic conditions in the hypolimnion are due in part to the process of plant growth and degradation, which consumes significant amounts of oxygen from the hypolimnion, which has no oxygen sources to replenish the losses. The anaerobic conditions are responsible for the addition of phosphorus to the water column from the sediments, which in turn enhance plant growth conditions. As a result, the water quality constituents requiring control immediately were identified as phosphorus and coliform bacteria.

RWQM was applied to simulate the transport of phosphorus and coliform in the Aberjona River, as a means of computing the loadings to Upper Mystic Lake. The result of the STORM simulations for runoff pollutant loads were input to RWQM at the appropriate locations, and values selected for simulation of units due to settling, dieoff, uptake, and other mechanisms. The results are long-term average loadings of phosphorus and coliform to the lake.

The lake loading for phosphorus was used as input to the Vollenweider input/output model, which classifies the existing phosphorus loading as eutrophic. In addition, the potential exists for coliform standards violations in the lake forebays. Several significant pollutant sources were identified:

1. particularly the CSOs and surcharging sanitary sewers in the Sweetwater Brook area and in Winchester, which are primarily responsible for the elevated coliform concentrations and are a significant phosphorus contributor;
2. the lake sediment sources of phosphorus; and
3. the Boat Club tributary.

A number of potential control alternatives were identified and preliminarily screened to narrow the list to a few that would be effective in reducing the pollutants and be affordable and implementable. The obvious action of eliminating the CSO and surcharging sewer sources would appreciably reduce the phosphorus and coliform sources. Urban runoff is a significant source of both phosphorus and coliforms, but its collection and treatment would be prohibitively expensive, and no programs exist to fund such projects. The pollutant loads from urban runoff could be reduced by effectively managing existing street sweeping and catch basin cleaning programs.

When the controls were screened, it was determined that most source controls were either too expensive or impractical; in-lake treatment alternatives, however, appear to be more attractive for the Upper Mystic Lake case. Lake aeration would eliminate the sediment phosphorus source; weed harvesting and floating plant collection would remove some of the plants that inhibit the recreational use of the lake and simultaneously remove a fraction of the nutrient load; and bottom covering along the shoreline would prevent rooted plant growth. Each of these controls attacks the symptom and not the source, but are effective means of achieving improved water quality conditions.

The remaining task is to evaluate in detail each of the alternative controls to determine which are most appropriate for implementation in the Upper Mystic Lake basin. Such an evaluation could be funded by the State or Federal Clean Lakes programs, as the Upper Mystic Lake should qualify for either. It will be important to carefully develop the application for either program, as the priority listing is a competitive process, and the investigation and implementation and operation of controls can be an expensive process.

Other methods of funding should be investigated, as the Clean Lakes programs have limited funds and are subject to budget cutbacks. Local means of funding include various types of user fees, rather than the property taxes, as the users of the lake would become previously responsible for the cleanup efforts. Whatever mechanisms for funding are developed, it is essential to have a strong local organization to promote the cause to the local and State officials responsible for prioritizing and funding the project.

Upper Mystic Lake will never be an oligotrophic body of water, but with implementation of the appropriate controls and an evolving program to expand the program as needed in the future, it will be possible to utilize the lake for recreational purposes well into the future.

APPENDIX A

MYSTIC NURP STUDY WATER QUALITY

Data may be found in DEQE Report "Upper Mystic Lake Watershed Urban Runoff Project: Main Report" Appendix A.

APPENDIX B

RESULTS OF FIRST FLUSH ANALYSIS

This Appendix contains results from the first flush analysis, which was conducted to determine whether constituent concentrations were greater at the beginning of the storm, tapering off as the storm progressed, thus exhibiting what is termed the first flush phenomenon.

Composite sample concentrations were averaged and plotted against the proportion of the storm that had passed when the composite was taken (percent of total storm runoff). Composited TSS, total phosphorus (TP), TKN, orthophosphate, nitrate and ammonia concentrations were plotted for samples taken at Mishawum Road, Washington Street, USGS gauge, Addison-Wesley and Hemlock Road. Some storms were characterized by four composites; in others only two. Figures B.1 through B.6 are the graphs developed in the analysis. For example, in Figure B.1, four composites were taken on the August 5, 1982 storm. Composited total phosphorus concentrations were 0.2, 0.06, 0.02 and 0.06 mg/l, respectively. The first composite (0.2 mg/l) represented about 33% of the storm. The first two composites cover about 60% of the storm. Thus, the composite concentrations were averaged $((0.2+0.06)/2 = 0.13)$ and plotted.

In some cases, first flush effects were observed; in other cases, concentrations increased as the storm progressed. The results of the analyses are presented and discussed in greater detail in Section 2.7.1 of this report.

FIGURE B.1--Composite Concentrations vs. Percent

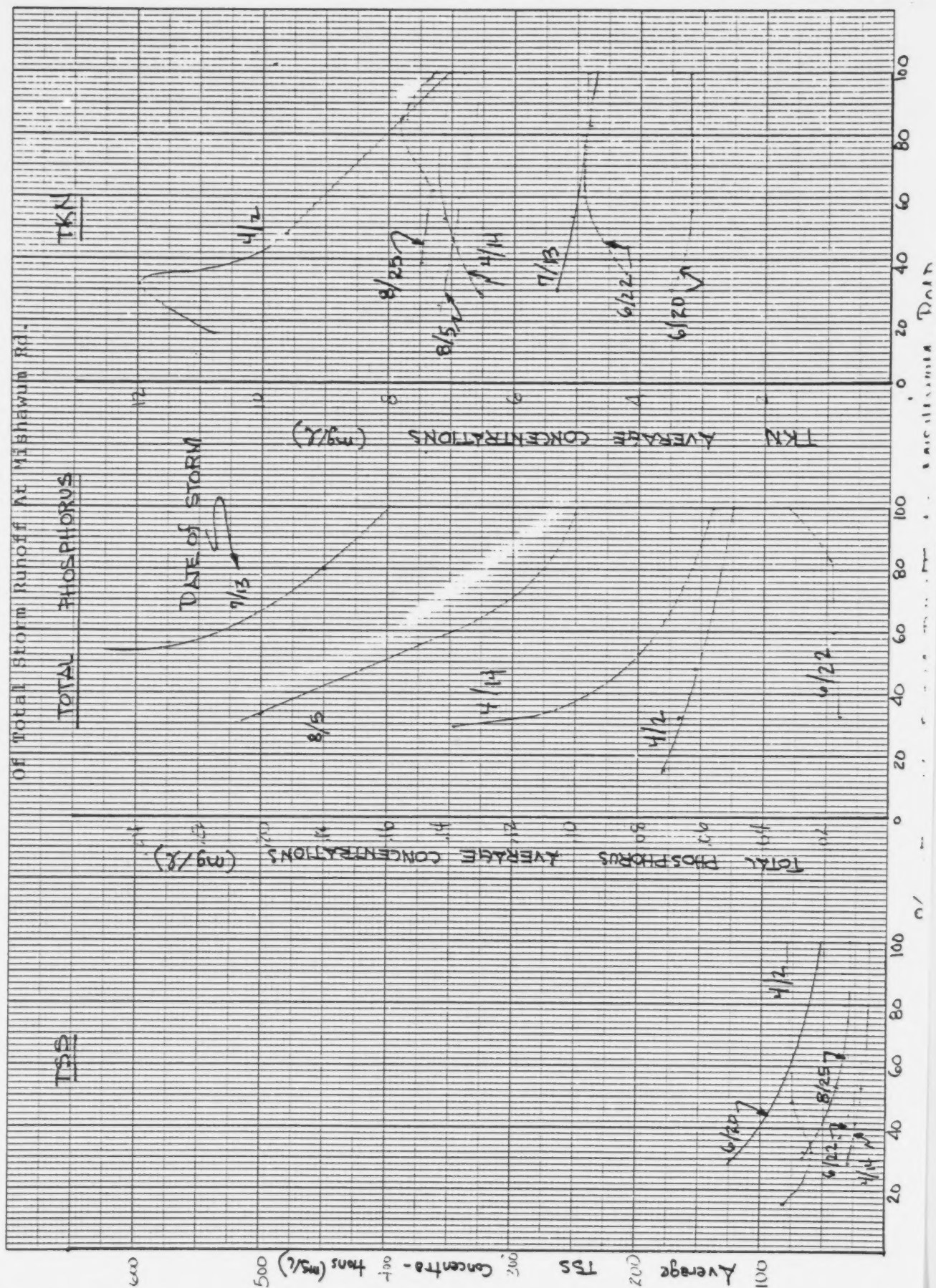


FIGURE B.2: Composite Concentrations vs. Percent of Total

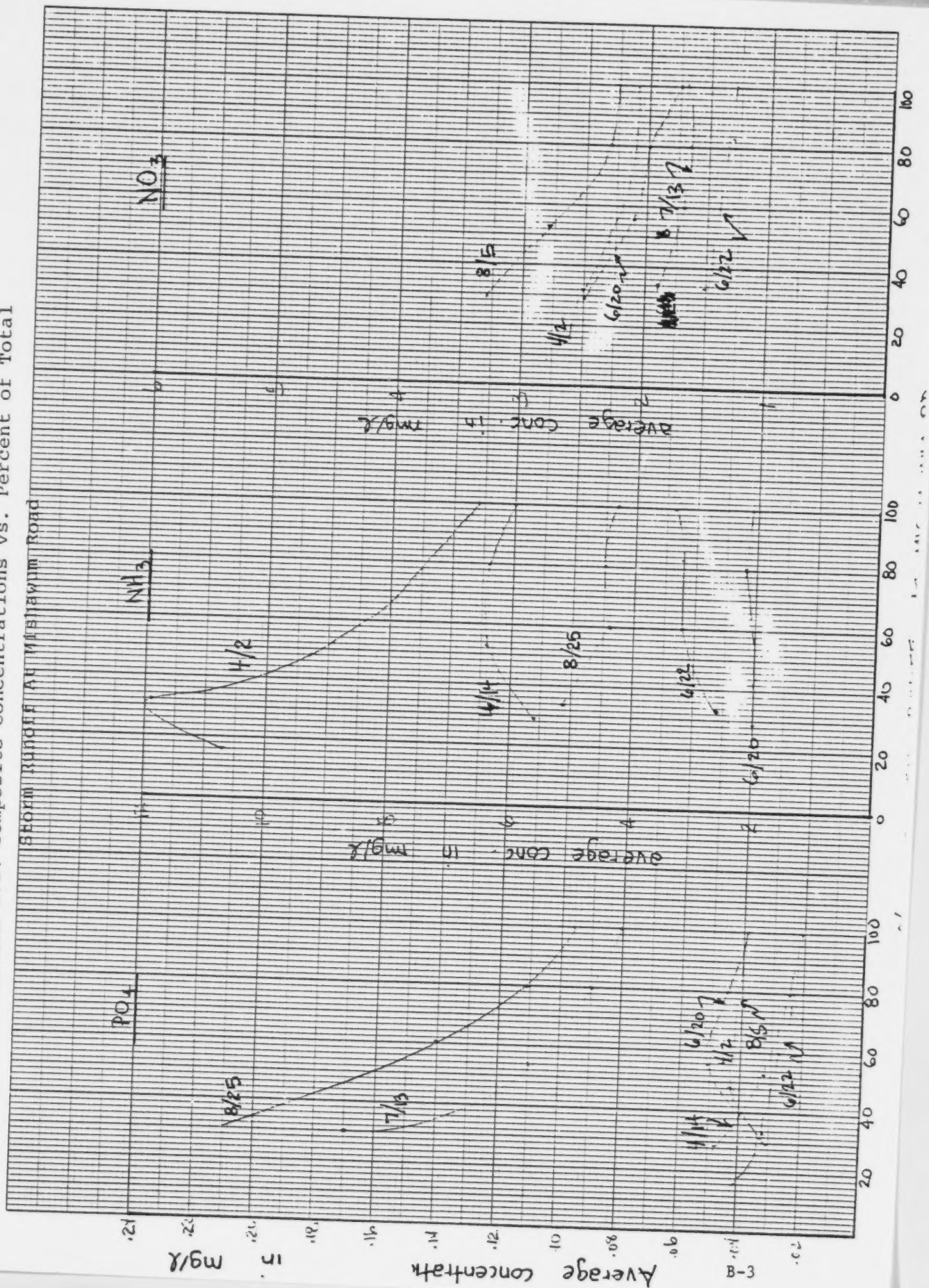


FIGURE B.3: Composite Concentrations vs. Percent of Total Storm Runoff at Washington Street

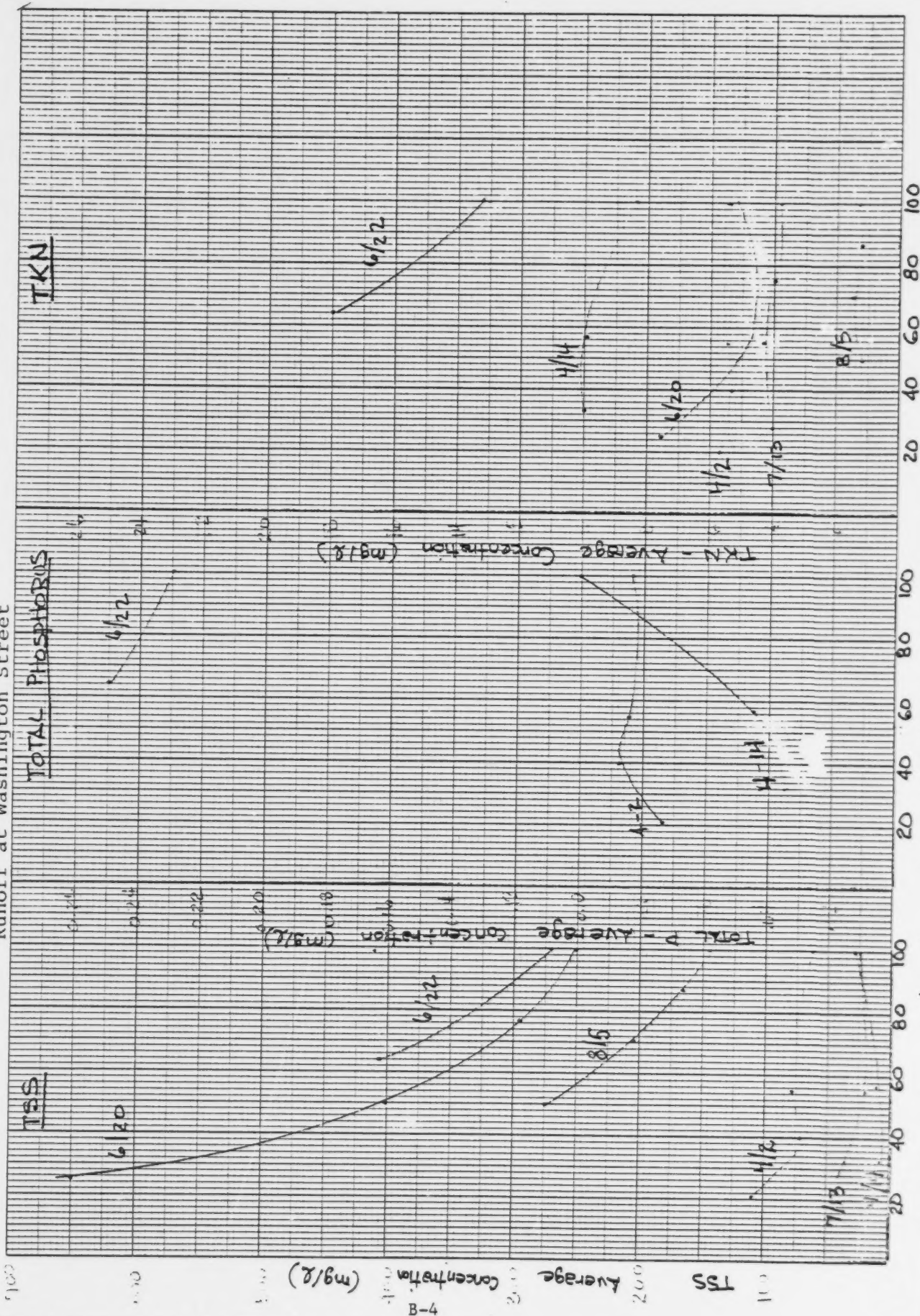


FIGURE B.4: Composite Concentrations vs. Percent of Total Storm Runoff At Washington Street

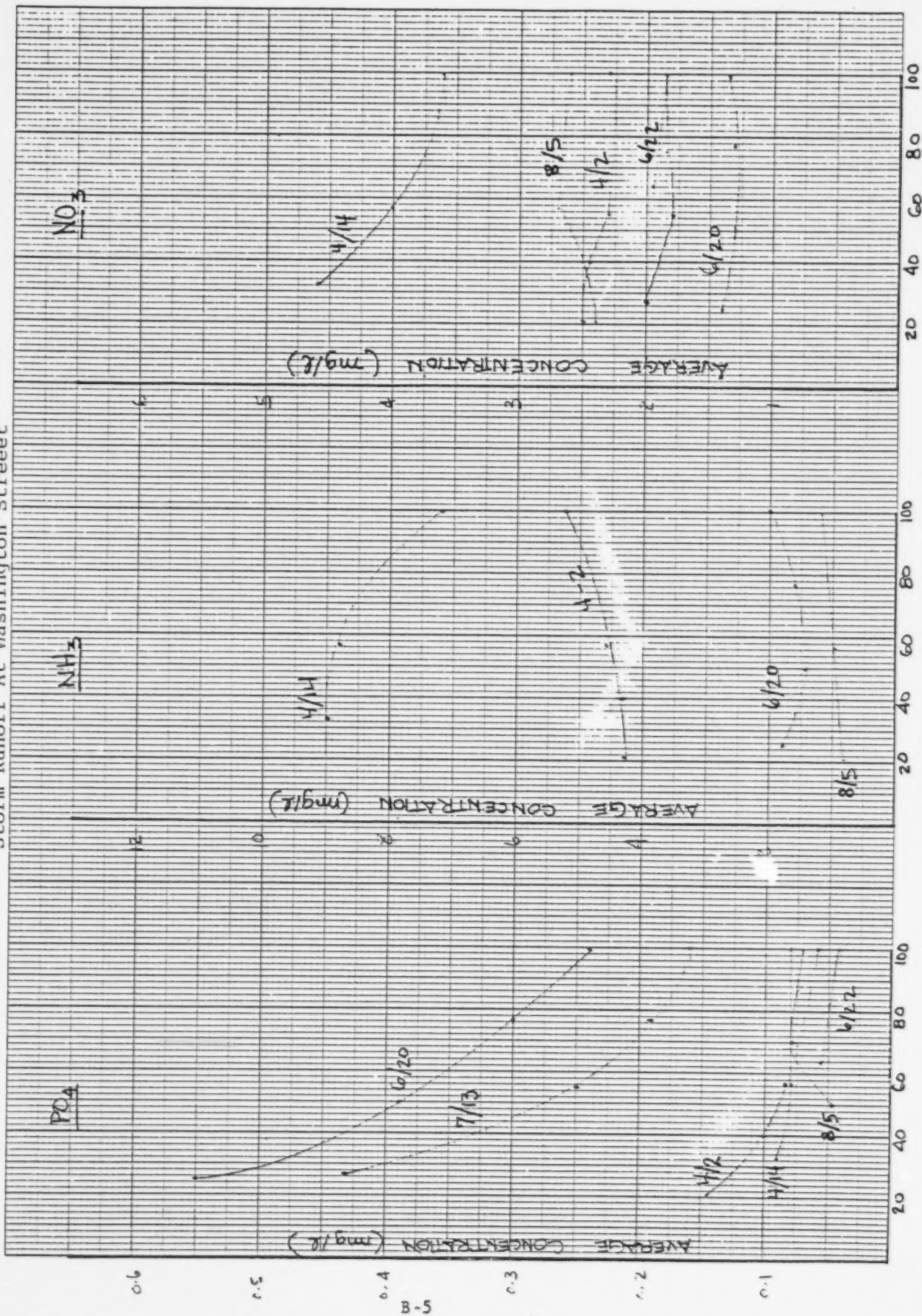


FIGURE B.5: Composite Concentrations vs. Percent of Total Storm Runoff At USSS Gauge

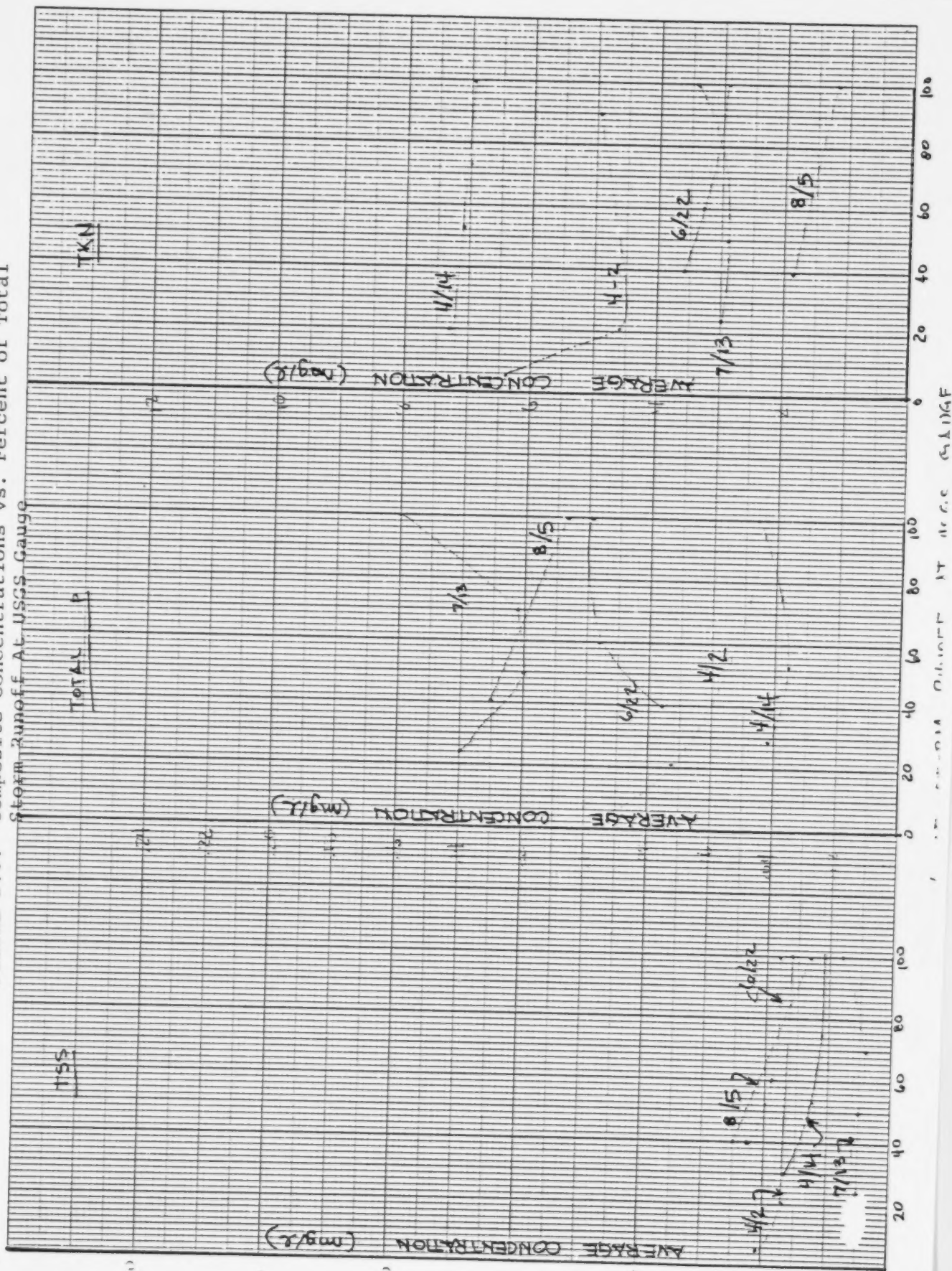
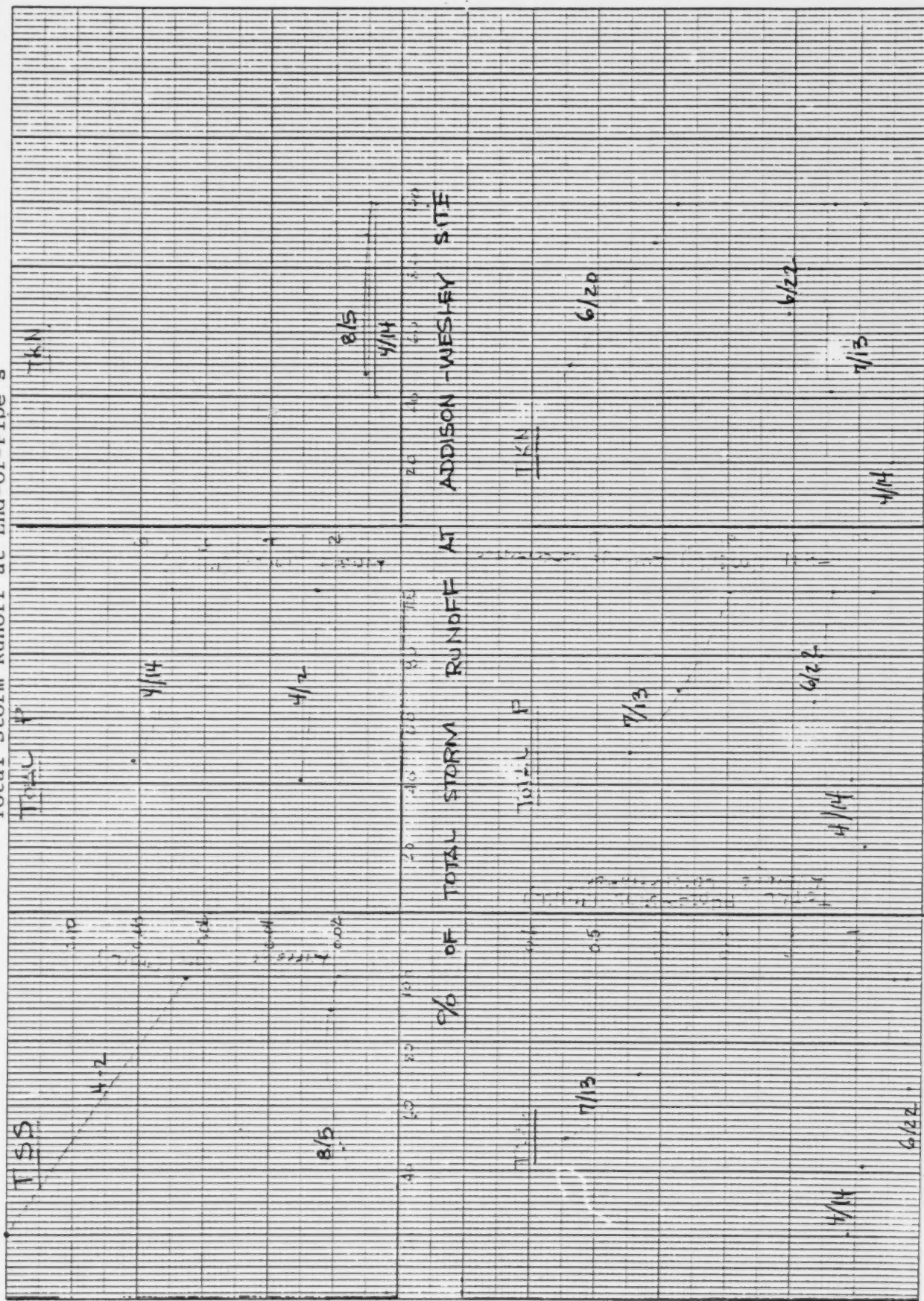


FIGURE B.6: Composite Concentrations vs. Percent of
Total Storm Runoff at End-Of-Pipe s



AT HENLOCK ROAD SITE

APPENDIX C

PERCENTILE CURVES

Percentile curves are tabulated summaries of occurrence frequencies for different pollutant concentrations. RWQM displays the curves for user-specified locations. The curves encompass results for the entire simulation period.

Figure C-1 presents the percentile curve divisions used for each curve. For example, there are ten phosphorus curve divisions of 0.1 mg/l each. Figure C-2 is a percentile curve for the calibrated simulation. Based on this curve, phosphorus concentrations were below the 0.2 mg/l (40th percentage unit) about 99 percent of the time. The remaining figures in Appendix C are percentile curves for different pollutant control strategies (e.g., clean up Sweetwater CSOs, and remove 90% of urban runoff coliform). All results are for the Sweetwater Brook-Aberjona River confluence (R.M. 3.3).

FIGURE C-1

Percentile Curve Divisions
for Phosphate and Coliform

<u>PERCENTAGE LIMITS</u>	<u>PO4 MG/L</u>	<u>COLIFORM 1000MPi/L</u>
MINIMUM	0.00	0.00
10.00	0.05	50.00
20.00	0.10	100.00
30.00	0.15	150.00
40.00	0.20	200.00
50.00	0.25	250.00
60.00	0.30	300.00
70.00	0.35	350.00
80.00	0.40	400.00
90.00	0.45	450.00
MAXIMUM	0.50	500.00

FIGURE C-2

Percentile Curves from the RWQM Simulation for Existing
Conditions with No Urban Runoff Management
Controls and No Remediation of Sweetwater Brook CSOs.

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	8.24	30.92
BELOW 20.0 PC	94.99	83.38
BELOW 30.0 PC	97.54	34.74
BELOW 40.0 PC	99.07	85.79
BELOW 50.0 PC	99.91	86.45
BELOW 60.0 PC	100.00	87.07
BELOW 70.0 PC	100.00	37.61
BELOW 80.0 PC	100.00	88.00
BELOW 90.0 PC	100.00	88.43
BELOW MAXIMUM	100.00	88.75

FIGURE C-3

Percentile Curves from RWQM Simulation for Revised
Conditions with Sweetwater Brook CSOs Connected
To A Sewage Treatment Plant

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	9.74	92.35
BELOW 20.0 PC	97.31	100.00
BELOW 30.0 PC	99.80	100.00
BELOW 40.0 PC	100.00	100.00
BELOW 50.0 PC	100.00	100.00
BELOW 60.0 PC	100.00	100.00
BELOW 70.0 PC	100.00	100.00
BELOW 80.0 PC	100.00	100.00
BELOW 90.0 PC	100.00	100.00
BELOW MAXIMUM	100.00	100.00

FIGURE C-4

Percentile Curves from the RWQM Simulation for Revised
Conditions with Urban Runoff Control Reducing
Coliform Concentrations in Stormwater by Ten Percent
And With Sweetwater Brook CSOs Connected
To A Sewage Treatment Plant

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	9.74	93.28
BELOW 20.0 PC	97.31	100.00
BELOW 30.0 PC	99.80	100.00
BELOW 40.0 PC	100.00	100.00
BELOW 50.0 PC	100.00	100.00
BELOW 60.0 PC	100.00	100.00
BELOW 70.0 PC	100.00	100.00
BELOW 80.0 PC	100.00	100.00
BELOW 90.0 PC	100.00	100.00
BELOW MAXIMUM	100.00	100.00

FIGURE C-5

Percentile Curves from the RWQM Simulation for Revised
Conditions with Urban Runoff Controls Reducing Coliform
Concentrations in Stormwater by Fifty Percent
And with Sweetwater Brook CSOs Connected to a
Sewage Treatment Plant

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	9.74	100.00
BELOW 20.0 PC	99.80	100.00
BELOW 30.0 PC	100.00	100.00
BELOW 40.0 PC	100.00	100.00
BELOW 50.0 PC	100.00	100.00
BELOW 60.0 PC	100.00	100.00
BELOW 70.0 PC	100.00	100.00
BELOW 80.0 PC	100.00	100.00
BELOW 90.0 PC	100.00	100.00
BELOW MAXIMUM	100.00	100.00

FIGURE C-6

Percentile Curves from RWQM Simulation for Revised
Conditions with Urban Runoff Controls Reducing
Coliform Concentrations by Ninety Percent and with
Sweetwater Brook CSOs Connected to a Sewage Treatment Plant

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	9.74	100.00
BELOW 20.0 PC	97.31	100.00
BELOW 30.0 PC	99.80	100.00
BELOW 40.0 PC	100.00	100.00
BELOW 50.0 PC	100.00	100.00
BELOW 60.0 PC	100.00	100.00
BELOW 70.0 PC	100.00	100.00
BELOW 80.0 PC	100.00	100.00
BELOW 90.0 PC	100.00	100.00
BELOW MAXIMUM	100.00	100.00

FIGURE C-7

Percentile Curves from RWQM Simulation for Revised
Conditions with Urban Runoff Controls Reducing Phosphate
Loads for Stormwater by Fifty Percent and with
Sweetwater Brook CSOs Connected to a Sewage
Treatment Plant

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	17.03	92.35
BELOW 20.0 PC	100.00	100.00
BELOW 30.0 PC	100.00	100.00
BELOW 40.0 PC	100.00	100.00
BELOW 50.0 PC	100.00	100.00
BELOW 60.0 PC	100.00	100.00
BELOW 70.0 PC	100.00	100.00
BELOW 80.0 PC	100.00	100.00
BELOW 90.0 PC	100.00	100.00
BELOW MAXIMUM	100.00	100.00

FIGURE C-3

Percentile Curves from RWQM Simulation for Revised
Conditions with Urban Runoff Controls Reducing
Phosphate Loads in Stormwater by Ninety Percent
And with Sweetwater Brook CSOs Connected to a
Sewage Treatment Plant

<u>PERCENTAGE LIMITS</u>	<u>P04</u>	<u>COLIFORM</u>
BELOW MINIMUM	0.00	0.00
BELOW 10.0 PC	23.25	92.35
BELOW 20.0 PC	100.00	100.00
BELOW 30.0 PC	100.00	100.00
BELOW 40.0 PC	100.00	100.00
BELOW 50.0 PC	100.00	100.00
BELOW 60.0 PC	100.00	100.00
BELOW 70.0 PC	100.00	100.00
BELOW 80.0 PC	100.00	100.00
BELOW 90.0 PC	100.00	100.00
BELOW MAXIMUM	100.00	100.00

APPENDIX D

Bibliography

1. Browne, F.X., "Nonpoint Sources," Journal of the Water Pollution Control Federation, Vol. 51, June 1979.
2. Camp Dresser & McKee, Inc., "CSO Study of Dorchester Bay", 1980.
3. _____, "Final Report on Assistance in Mathematical Modeling," June 1982.
4. _____, "Mystic Hydrology Study," 1981.
5. Mattraw, H.C., Jr., and Sherwood, C.B., "Quality of Stormwater Runoff from a Residential Area, Broward County, Florida," USGS Journal of Research, Vol. 5, 1977.
6. McGauhey, P.H., Engineering Management of Water Quality, McGraw-Hill, Inc., New York, 1968.
7. McKee, J.E. and H.W. Wolf, Water Quality Criteria, 2nd edition, Report to California State Water Quality Control Board, SWPCB Publication 3B, 1963.
8. Metropolitan District Commission, "Mystic River Watershed: Water Quality Surveys," 1979, 1980.
9. Polls, I. and Lanyon, R., "Pollutant Concentrations from Homogeneous Land Uses," ASCE Journal of the Environmental Engineering Division, Vol. 106, February 1980.
10. U.S. Department of Commerce, "Climatic Atlas of the United States," 1974.
11. U.S. Public Health Service, "Public Health Service Drinking Water Standards", revised 1961.
12. Uttormark, Paul D., Hutchins, M.L., "Input/Output Models as Decision Aids for Lake Restoration," Technical Completion Report Project C-7232, Land and Water Resources Institute, University of Maine, April 1978.